Chapter II

RELATIONSHIP TO POLLUTION OF PLANKTON

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ECOLOGY OF PLANT SAPROBIA

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The present report contains a listing of approximately 300 plant organisms of importance for the self-purifying capacity of our native waters. In order to express their dependence on decomposing organic nutrients, we introduced in 1902 (1) the term "saprobia" for them and subdivided them into poly-, meso- and oligosaprobia in accordance with the increasing degree of mineralization in such waters.

Such a classification presupposes that the respective organisms are uniquely dependent, within relatively narrow limits, on the chemical composition of the water for their distribution and development in situ. The Institute mentioned has available a very large number of analyses of the composition of a great many different bodies and courses of water and many years of investigation have shown that this assumption is valid if we take into account in such a classification an ecology which assigns a higher value to the occurrence of floristic constituents -- insofar as these develop typically -- than the determination of merely isolated specimens. The present case therefore concerns a classification of aquatic plants on a chemo-physiological basis in which laboratory tests are less decisive than the findings in situ of their presence. Such locations are collectors or channels for raw putrescible sewage, filtered effluents from trickle fields or biological oxidation, settling or collecting tanks absorbing nutrient-containing inflow as well as overgrown ponds, cisterns and dry wells.

For reasons of lack of space, we have temporarily omitted from consideration the organisms of pure water (catharobia), specifically their plankton and also because the term saprobia is hardly applicable to them as in the case of a number of algae from pure mountain streams and lakes. Here we should point out that our present observations indicate that there are very few chlorophyll-containing organisms which refuse any organic nutriment under natural conditions and that there are hardly any surface waters which do not react to permanganate through their content of organic substances.

The already mentioned extensive and definitive influence of aquatic organisms, especially when microscopic, has already been utilized by Ferd. Cohn to a limited extent for the evaluation of the degree of purity of these waters as a function of the organisms existing in them. This method of biological analysis was therefore developed in the botanical field. With its further development must be credited Mez, Schorlein, Lindau, Schmidmann (by founding the Institute mentioned), Schiemenz and Hofer among many others.

The large-scale experiments most appropriate for testing the relation between organisms and the character of the water have steadily increased in Germany since 1870 by reason of the increased outflow from the sewers of the growing towns and cities and through the increased volume of sewage from industrial agricultural enterprises. Obviously, methods of purification have been perfected at the same time which have also lead to valuable and pertinent experimental findings. In spite of certain differences in chemical composition, all these effluents produce the same biological picture in general in the collectors because a stream or lake tends to compensate the existing differences by dilution, neutralization, oxidation, etc. and thus creates the same similar nutritive conditions for saprobia.

A detailed discussion of the considerations in classifying the organisms contained in the attached list into the respective zones will follow in the Reports of the Institute, together with a discussion of the respective animals and with the addition of illustrations. In this report here, we assume familiarity with all the organisms listed as well as the knowledge of their general habitat within the three typical regions of bank, bottom (benthos) and open water (plankton) and limit ourselves to giving a brief characteristic of the three different zones.

I - The zone of polysaprobia is characterized from the biological viewpoint principally through the wealth of schizomycetes by number, species and variety. Polysaprobia may gradually overlap into the zone of mesosaprobia (cf. Spherotilus) but will never occur grouped in the oligosaprobiotic zone but only in isolation and then generally erratically. The overlapping of Spherothilus into the second zone finds its reason in the fact that Spherotilus is an inhabitant of running water and needs aeration in addition to motion.

Designations such as "in pure and impure water" or "Euglena viridis is found in all Euglenaceae habitats" are offenses against the ecological viewpoint in our system. The number of germs capable of development per cubic centimeter of standard nutrient gelatine can easily rise above 1 million. Our standard food fishes can become easily subject to asphyxiation in this zone.

From the chemical viewpoint, the zone of the polysaprobia is characterized by the predominance of reduction and cleavage processes, through absence or low content of oxygen, through an abundance of carbondioxide and a relatively high content of nitrogenous and putrescible nutrient substances. The mud of this zone is frequently rich in ferrous sulphide.

We have no large streams of polysaprobiotic character over any great distance; even the river "Wupper" is not polysaprobiotic.

II - In the zone of the mesosaprobia, we distinguish sections with strong and/or weak mesosaprobiotic character. In the former of the two, self-purification seems to take place more aggressively than in the latter.

From the biological viewpoint, the first part of this zone is characterized by the predominance of Schizophyceae and -- especially in moving water -- by a more or less great abundance of Eumecytes; Peridiniales are practically completely absent. Animal life may be rather fully developed and thus may attract fishes for feeding. The fishes are here subject to asphyxiation only infrequently. The numerical content of bacteria per cubic centimeter is still high and may run into hundreds of thousands.

Good examples for this formation are furnished in particular by contaminated ponds and ditches, expecially of trickle fields.

In contrast to the symbioses described so far and in special consideration of the benthonic diatoms, we might designate the second part of the mesosaprobiotic zone as the formation of the Bacillariaceae, especially if we consider the dearth of varieties in the strong mesosaprobiotic zone. In addition to the diatoms, we find here in general, however, a rather wide classification of the vegetation, e.g., among the Chlorophyceae, so that on the whole given types do not necessarily predominate.

The number of bacteria developing on standard nutritive gelatine normally amounts to less than 100,000.

All mesosaprobia are resistant to a minor affluence of sewage. Many of the higher aquatic plants find, particularly beyond the weak mesosaprobiotic zone, adequate and often rather favorable conditions of vegtation. The progressive course of self-purification is as characteristic from the chemical as from the biological viewpoint. Aeration and production of oxygen through assimilation of carbon have made possible the inception of oxidation processes which favor the life of the coarser fauna as already mentioned. Especially in the strong mesosaprobiotic part, the oxygen content tends to decrease, however, in darkness or with a clouded sky but rises again and often beyond the saturation maximum under increased light.

Such decomposition products of protein as asparagin, leucine, and glycine (all characterized by NH_4- and CCOH-groups, i.e., decomposition and oxidation stages) appear to be widely present in this zone (but in great dilution which makes their demonstration rather difficult) as well as ammonia salts and -- when approaching the oligosaprobiotic formation -- nitrites and nitrates, the oxidation stages of ammonia.

When stored in flasks, normal water from this zone does not tend to putrefy but may form a minor supernatant layer under certain circumstances.

Normal effluent from the trickle fields which may be designated -- at least during the hot season -- as typically nitrous water should probably be counted in the weak mesosaprobiotic region.

III - The zone of the oligosaprobia is characterized by the termination of mineralization and all aggressive processes of self-purification are normally absent here. The biological organization is manifold. If they exist, Peridiniales reach typical development in a few representatives. Sensitive to sewage, Charales now begin to show themselves but polysaprobia are absent even in small amounts. The number of bacteria developing on standard nutritive gelatine usually is less than 1,000 per ccm unless erratic forms have been infused. The dearth of planktonic Schizomycetes is also characteristic. Given benthonic forms of this class may occur, however, typically in the organic matting of the banks.

Chemical analysis of the waters from this zone shows us that the consumption of permaganate is relatively low and that we find only traces of organic nitrogen. Determined in a suitable manner, the consumption of oxygen is minor. Measured by immersing a white disk, the transparency of the water is generally high in calm weather. The mud from this region is generally poor in reduction processes but may assume a mesosaprobiotic character. In general, mud that can be characterized as oligosaprobiotic, will probably not be widely distributed.

Since the rapid decomposition of organic substances no longer dominates the chemistry of this region, less obviously effective substances may have an influence on ecological composition, e.g., such minerals as determine the differing hardness of the waters. However, there do not exist as yet any complete observations on this, not even for Phanerogamia.

The waters of all the above zones nearly all show an alkaline reaction; those with an acid reaction we intend to describe similar to the above at some later time.

We intend to publish elsewhere the "Ecology of Animal Saprobia" which is in harmony with our system.

PHYSIOLOGICAL SYSTEM OF PLANT SAPROBIA

Within the individual zones, the organisms are arranged in accordance with the Engler System, except for some deviations in the flagellate group. The following listing is based only on our own observations from nature. Such organisms as we did not ourselves observe at the main source of their development, have not been taken into account even if pertinent notes on them existed in literature; those have been omitted also which have no biocenotic value for the present purposes on the basis of our present experience (e.g., Bacterium cellulosae Omelianski Mig., many pantotrophic bacteria and various phanerogamia).

Doubts on the exact place of classification of some of the organisms were resolved by allocating them to the less nutrient of the respective zones.

I. Polysaprobia

Schizomycetes
- Spirillum tenue Ehrbg.
- " serpens (O. F. Müller).
- " Rugula (O.F. Müller).
- " Undula Ehrbg.
- " volutans Ehrbg.
- Sphaerotilus natans Ktz. / " roseus Zopf — cf. Mesosaprobia
- Zoogloea ramigera Itzigsohn.
- Streptococcus margaritaceus Schröter.
- Sarcina paludosa Schröter
- Beggiatoa alba (Vaucher) Trevisan
- " leptomitiformis (Mengh.) Trevisan.
- " arachnoidea (Ag.) Rabenhorst.
- Thiopolycoccus ruber Win.
- Chromatium okenii (Ehrbg.) Perty. / " vinosum (Ehrbg.) Win. / " minutissimum Win. / Lamprocystis roseo-persicina (Ktz.) Schröter. — cf. Mesosaprobia

Schizophyceae
- Arthrospira jenneri Stitz., when associated with Beggiatoa. cf. Mesosaprobia.

Euglenales
- Euglena viridis (Schrank)Ehrenbg., when abundant.

Protococcales
- Polytoma uvella Ehrbg.

II. Mesosaprobia

1. Strong Mesosaprobiotic

Schizomycetes
- Sphaerotilus natans Ktz. / " roseus Zopf — when associated with mesosaprobiotic Bacillariaceae and when in part with Cladothrix-like ramification. cf. Polysaprobia.
- Thiothrix nivea (Rabenhorst) Win.
- Chromatium okenii (Ehrbg.) Perty / Lamprocystis roseo-persicina (Ktz.) Schröter — when associated with mesosaprobiotic algae. cf. Polysaprobia.
- Thiospirillum sanguineum (Ehrbg.) Win.
- Spirochaete plicatilis Ehrbg., is classed by us as animal.

Schizophyceae
- Oscillatoria princeps Vaucher
- " tenuis Ag.
- " chalybea Mertens.
- " putrida Schmidle.
- " chlorina Kutz
- " splendida Grev.
- " brevis Ktz.
- " formosa Bory.
- Arthrospira jenneri Stitz. cf. Polysaprobia.
- Phormidium uncinatum (Ag.) Gomont.
- " autumnal (Ag.) Gomont.
- " foveolarum (Mont.) Gom.

Cryptomonadales
- Cryptomonas nordstedtii (Hansg.) Senn; probably = Cryptoglena coerulescens Ehrbg.

Euglenales
- Euglena viridis var. lacustris Francé.
- Lepocinclis ovum Ehrbg.
- " texta (Dug.) Lemm.
- Cryptoglena pigra Ehrbg.

Bacillariales
- Hantzschia amphioxys (Ehrbg.) Grun.
- Nitzschia palea (Kutz.) W. Sm. and their variety fonticola Grun.
- Stauroneis acuta W. Sm.

Protococcales
- Chlamydomonas de baryana Gorosch.
- Spondylomorum quaternarium Ehrbg.
- Stichococcus bacillaris Naeg F. confervoidea Hazen. cf. weak mesosaprobia.
- Chlorella infusionum (Beyerk.).

Confervales
- Ulothrix subtilis Kuetz. forma.
- Stigeoclonium tenue Ktz. (delimitation of variety difficult) attenuates toward weak mesosaprobiotic zone.

Phycomycetes
- Mucor, and Zygorhynchus group.
- Apodya lactea (Ag.) Cornu - Leptomitus lacteus Ag.

Hemiascomycetes
- Endoblastoderma salmonicolor Fischer & Brebeck and some Torula which probably belong here.

Euascomycetes
- Fusarium aquaeductuum Lagerheim.

2. Weak mesosaprobiotic

Schizomycetes
- Lampropedia hyalina (Ehrbg.) Schröter.
- Cladothrix dichotoma Cohn.

Schizophyceae
- Oscillatoria limosa Ag.
- " antliaria Jurgens
- Phormidium subfuscum Ktz.
- Aphanizomenon flos aquae Ralfs.

Chrysomonadales
- Chrysosphaerella longispina Lauterb
- Synura uvella Ehrbg., when associated with Closterium acerosum, Brachionus, Rotifer, actinurns and isolated specimens of Euglena viridis. cf. Oligosaprobia

Cryptomonadales
- Cryptomonas crosa Ehrbg.
- " ovata "

Euglenales
- Euglena acus Ehrbg.
- " spirogyra Ehrbg.
- " oxyuris Schmarda.
- " deses Ehrbg.
- " pisciformis Klebs
- " quartana Moroff.
- " tripteris (Duj.) Kl.
- " velata Klebs.
- Phacus caudata Hübner.
- Trachelomonas hispida Stein.
- " volvocina Ehrbg.
- Colacium vesiculosum (Ehrbg.) Stein

Peridiniales
- Ceratium tetraceros Schrank, occurs also associated with Lamprocystis, Chromatium okenii.

Bacillariales
- Melosira varians Ag. (preferred mineralized organic substance).
- Stephanodiscus hantzschianus Grun
- " " var. pusillus Grun.
- Diatoma vulgare Bory.
- Synedra Ulna var. splendens (Ktz.) J. Brun.
- " actinastroides Lem.
- " radians (Ktz.) Grun.
- " vaucheriae Ktz.
- Microneis minutissima (Ktz.) Cleve.
- Navicula brebissonii Ktz.
- " radiosa Ktz.
- " cryptocephala Ktz.
- " rhynchocephala Ktz.
- " cuspidata Ktz.
- " mesolepta Ehrbg.
- " amphisbaena Bory.
- " ambigua Ehbg.
- " atomus Naeg.
- Stauroneis phoenicenteron Ehrbg.
- Gomphonema tenellum W. Sm.
- " olivaceum Ktz.
- " parvulum Ktz.
- Rhoicosphenia curvata (Ktz.) Grun.
- Nitzschia parvula W. Sm.
- " communis Rabh.
- " stagnorum Rabh.
- " dissipata (Ktz.) Grun.
- " acicularis (Rabh). W. Sm.
- Surirella ovalis Breb. var. ovata = S. ovata Ktz., also var. minuta and angusta.

Conjugatae
- Closterium acerosum Ehrbg.
- " parvulum Naeg.
- " moniliferum Ehrbg.
- " leibleini Ktz.
- Cosmarium botrytis Menegh.
- Spirogyra crassa Ktz.
- " porticalis (Vauch.) Cleve.

Protococcales
- Carteria cordiformis Dill.
- Chlamydomonas ehrenbergi Gorosch.
- " brauni Gorosch.
- " reinhardi Dang.
- " kuteinikowi Gorosch.
- " reticulata Gorosch.
- Chlorogonium euchlorum Ehrbg.
- Gonium sociale (Dng.) Warm. = Gonium tetras A. Br.
- Stichococcus bacillaris Naeg; cf. strong Mesosaprobia.
- Chlorococcum botryoides Rabh.
- Pediastrum boryanum (Turp.) Menegh., especially when numerous young specimens exist.
- Rhaphidium polymorphum var. aciculare (A.B.) Rab.
- Scenedesumus auadricauda (Turp.) Bréb.
- " acuminatus (Lagh.) Chodat.
- " obliquus (Turp.) Ktz.
- " bijugatus (Turp.) Ktz.

  especially when numerous young specimens exist.
- Selenastrum bibraianum Reinsch.
- Dictyosphaerium pulchellum Wood.
- " ehrenbergianum Naeg.
- Chlorosphaera limicola Beyrk.

Confervales
- Ulothrix subtilis (Ktz.); cf. Oligosaprobia.
- Conferva bombycina (Ag.) Wille.
- Microthamnion kuetzingianum Naeg.
- Oedogonium species.
- Cladophora crispata Ktz.
- Vaucheria sessilis (Vauch.) D.C.

Florideae
- Hildebrandia rivularis (Liebm.) Bréb.

Monocotyledoneae
- Holodea (Elodea) canadensis R. & Mchx.
- Lemna minor L.
- " polyrhiza L.

Dicotyledoneae
- Ceratophyllum demersum L., when in certain forms of growth.

III. Oligosaprobia

Schizomycetes
- Chlamydothrix ochracea (Ktz.) Mig.
- Gallionella ferruginea Ehrbg.
- Crenothrix polyspora Cohn.
- Clonthrix fusca Roze.

Schizophyceae
- Dactylococcopsis rhaphidioides Hansg.
- Coelosphaerium kuetzingianum Naeg.
- Gomphosphaeria lacustris Chodat.
- Microsystis incerta Lemm.
- Clathrocystis aeruginosa (Ktz.), Henfrey and other Microcystis-varieties.
- Merismopedia glauca (Ehrbg.) Naeg.
- " convoluta Bréb.
- Oscillatoria anguina Bory.
- " rubescens D. C.
- " agardhii Gom.
- Phormidium inundatum Ktz.
- " papyraceum (Ag.) Gom.
- Microcoleus subtorulosus (Bréb.) Gom.

Anabaena flos aquae (Lyngb.) Bréb.
" spiroides Kleb.
Glaucothrix gracillima Zopf.
Calothrix parietina (Naeg.) Thuret.

Chrysomonadales
Chromulina rosanoffii Woron.
Mallomonas acaroides Perty.
" producta (Zach.) Iwanoff.
Synura uvella Ehrbg.; cf. mesosaprobia.
Uroglena volvox Ehrbg.
Dinobryon species.

Euglenales
Euglena oblonga Schmitz.
" geniculata (Duj.) Schmitz.
" minima Francé.
Phacus longicauda (Ehrbg.) Duj.
" pleuronectes Nitzsch.
" parvula Klebs.
" pyrum (Ehrbg.) St.

Peridiniales
Gymnodinium palustre Schilling.
Ceratium hirundinella O.F. Müll.
Peridinium minimum Schilling.
" quadridens Stein.
" cinctum Ehrbg.
" tabulatum Clap. & Lachm.
" berolinense Lemm.
" bipes Stein.
Gonyaulax apiculata (Pen.) Entz.

Bacillariales
Melosira ambigua O. Müll.
" granulata (Ehrbg.) Ralfs.
" italica Ktz.
" binderiana Ktz.
" crenulata Ktz.
" arenaria Moore and other species
Cyclotella meneghiniana Ktz.
" kuetzingiana Thw.
" comta (Ehrbg.) Ktz.
Tabellaria flocculosa (Roth) Ktz.
Meridion circulare Ag.
Fragilaria virescens Rulfs.
" construens (Ehrbg.) Grun.
" mutabilis (W. Sm.) Grun.
Asterionella formosa Hass.
Synedra acus Ktz.
Syedra ulna (Nitzsch) Ehrbg. and varieties
Eunotia arcus (Ehrbg.) Rabh.
Achnanthes exilis Ktz.
Navicula mesolepta Ehrbg.
" viridis Ktz.
" maior Ktz.
" gibba Ehrbg.
" dicephala W. Sm.
" inflata Ktz.
" iridis Ehrbg.
" limosa Ktz.
" gastrum Ehrbg.
" hungarica Grun.
" perpusilla Grun.
" viridula Ktz.
" clausii Gr.
Pleurosigma attenuatum (Ktz.) W. Sm.

Gomphonema acuminatum Ehrbg.
" capitatum Ehrbg.
" constrictum Ehrbg.
" angustatum Ktz.
Cymbella ehrenbergii Ktz.
" cistula (Hempr.) Kirchn.
" lanceolata (Ehrbg.) Kirchn.
Encyonema prostratum Ralfs.
" ventricosum Ktz.
Amphora ovalis Ktz.
Epithemia turgida (Ehrbg.) Ktz.
" sorex Ktz.
" zebra (Ehrbg.) Ktz.
Rhopalodia gibba (Ktz.) O. Müller
Bacillaria paradoxa Gmelin
Nitzschia sigmoidea (Ehrbg.) W. Sm.
" linearis (Ag.) W. Sm.
" vermicularis (Ktz.) Grun.
" vitrea Norman.
Cymatopleura elliptica (Bréb) W. Sm.
" solea (Bréb) W. Sm.
Surirella biseriata Bréb.
" splendida Ktz.

Conjugatae
Closterium lunula Ehrbg.
" dinanae Ehrbg.
" ehrenbergii Menegh.
" areolatum Wood.
Staurastrum tetracerum Ralfs.
Spirogyra irregularis Naeg.
" nitida (Dillw.) Linck.
" gracilis Ktz.
Mougeotia genuflexa (Dillw.) Ag.

Protococcales
Chlamydomonas angulosa Dill.
" intermedia Chod.
" longistigma Dill.
" pisiformis Dill.
" variabilis Dang.
Eudorina elegans Ehrbg.
Pandorina morum Bory.
Volvox globator L.
Carteria obtusa Dill.
Lobomonas francei Danj.
Pteromonas alata (Cohn) Seligo
Phacotus lenticularis Stein.
Tetraspora gelatinosa (Vauch.) Desv.
" explanata Ag.
Dimorphococcus lunatus A. Br.
Rhaphidium polymorphum Ktz.; parallel to Mesosaprobia.
Richteriella botryoides (Schmidle) Lemm.
Protococcus botryoides (Ktz.) Kirchn.
Pediastrum duplex Meyen.
" kawraiskyi Schmidle.
" tetras (Ehb.) Ralfs.
" Rotula (Ehb.) A. Br.
Actinastrum hantzschii Lagerh.
Coelastrum microporum Naeg.
" reticulatum (Dang.) Senn.
Sphaerocystis schroeteri Chod.
Hydrodictyon utriculatum (L.) Lagerh.
Botryococcus braunii Ktz.

Confervales

Ulothrix variabilis Ktz.
" subtilis var. variabilis (Ktz.) Kirchn.; cf. Mesosaprobia.
" zonata (Web. & Mohn) Ktz.
Draparnaldia glomerata (Vauch.) Ag.
" plumosa (Vauch.) Ag.
Chaetophora elegans (Roth) Ag.
Bulbochaete setigera Ag.
Coleochaete pulvinata A. Br.
Rhizoclonium hieroglyphieum (Ag.) Ktz.
Cladophora glomerata Ktz.
Vaucheria species.

Florideae
Lemanea torulosa (C. Ag.) Sirodot
Batrachospermum moniliforme Roth.

Bryophyta
Fontinalis antipyretica L.
Amblystegium riparium Schimp.

Pteridophyta
Salvinia natans All.
Isōetes lacustris L.

Monocotyledoneae
Potamogeton pectinatus L.
" crispus L.
Lemna trisulca L.

Dicotyledoneae
Nuphar lutenum Sm.
Nymphaea alba L., particularly the former is resistant to a great volume of sewage but does not indicate it.

In addition to the Oligosaprobia listed here, there are many others but these are less important for the evaluation of water.

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Further literature references and historical data will be found in these publications and further issues of the Institute.

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EFFECT OF SUNLIGHT AND GREEN ORGANISMS* ON RE-AERATION OF STREAMS

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The diurnal changes of dissolved oxygen in running streams were studied. The oxygen increased rapidly during the morning hours, reaching a maximum in the afternoon and a minimum at the early morning hours just before sunrise. The variations were similar in a tidal section of the Delaware, but were somewhat affected by the changes in tides.

Laboratory experiments with river water containing green algae showed that small temperature changes had practically no effect, the dissolved oxygen increasing or decreasing depending upon light and darkness. Direct sunlight was not an important factor, because increases were equally great with diffused light and with direct sunlight. The dissolved oxygen in water containing large quantities of blue-green and green algae could be decreased from supersaturation to 17 per cent saturation by placing the water in darkness, and could also be increased to 282 per cent saturation by subjecting it to diffused light. Changes in pH values followed changes in oxygen saturation. Under similar conditions the oxygen dissolved could be decreased by

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half when the number of organisms was decreased by half. Sampling during the afternoon of polluted rivers containing green organisms leads to erroneous results. In stream-pollution surveys all factors must be taken into consideration.

Organisms containing the green pigment chlorophyll are capable of synthesizing complex organic compounds from carbon dioxide and water and giving off oxygen. This process, photosynthesis, takes place only in the presence of light. The first product of the process is presumably formaldehyde, from the condensation of which sugars and starches are formed. Aquatic plants capable of synthesizing their own food in this manner, and encountered in the streams, are mostly algae.

Some of the factors that influence photosynthesis are light intensity, temperature, partial pressure of carbon dioxide, and aeration. Light, especially the ultra-violet rays, stimulates the growth and activities of the green and blue-green algae. In turbid waters the penetration of light is reduced and hence photosynthesis is reduced. On the other hand, in a clear stream penetration of light is much greater and photosynthesis can take place at considerable depths.

The presence of carbon dioxide is also essential for photosynthesis. This may be replenished from the air or from the carbon dioxide produced as a result of respiration and bacterial activity. In the absence of free carbon dioxide plants may utilize the bicarbonates.

If conditions are favorable for photosynthesis, the oxygen content of the water will increase sometimes far beyond saturation. During the dark hours oxygen is consumed and carbon dioxide given off. During daylight the process is reversed. Actually during the day, then the oxygen concentration in a stream is the balance between these two processes -- the rate at which oxygen is liberated by the activities of green organisms and the rate at which it is consumed by respiration and oxidation. During the night, however, there will not be any liberation of oxygen, but the consumption will go on unabated with the result that the oxygen saturation will be lower. If the pollution in a stream is relatively great, the consumption of oxygen will overbalance its production and there will be depletion of oxygen. If, on the other hand, the pollution is slight, there may be a supersaturation of oxygen.

The green algae are most abundant in water during the summer. Their development follows the curve of the temperature of water, and maximum growth occurs in July and August. The optimum temperature for their growth is between 15° and 25° C., although some species can tolerate extreme heat or cold. The blue-green algae are also abundant during the summer months, although their maximum growth often occurs a little later in the season and some of them can tolerate somewhat higher temperatures than the green algae.

Although these changes in algal growth and the subsequent changes in dissolved gases in the water have been known for a long time, actual observations and determinations of diurnal changes in running streams have been reported only in a few instances. An observation made on the Illinois River (1909) was reported without much comment. Butcher, Pentilow, and Woodley (2) have given detailed studies on two polluted rivers in England. The studies by Birge and Juday (1) on the inland lakes of Wisconsin, although dealing with the changes taking place, were not concerned with running river water. Duvaux (4) and Duval and Dumarand (3) have discussed the mechanism and the rate of reaction changes in connection with the gaseous exchange of submerged aquatic plants. Moore (5) has published some observations on certain marine organisms in reaction to light, and Saunders (6) has published a note on photosynthesis and hydrogen-ion concentration. Several other investigators have dealt more remotely with the subject in hand, but none made an attempt to correlate the changes observed in the laboratory with actual conditions in streams.

It was with the purpose of evaluating the role of these green organisms in the re-aeration of the Delaware, Connecticut, and Raritan rivers that these studies were undertaken, but only some results obtained with the Delaware River water are here presented.

METHODS

Data obtained by sampling the river at definite places for 24-hour periods included temperature, dissolved oxygen, biochemical oxygen demand, and B. coli. Samples were taken in the middle and two quarter points of the river at mid depth. For the laboratory experiments large samples were obtained from different points in the Delaware River. Some samples were exposed to light or kept in the dark in open containers with uniform depth. Others were distributed into glass-stoppered bottles, which were immersed in a water bath and the temperature regulated with hot and cold water. At frequent intervals (1 to 1-1/2 hours) the temperature and dissolved oxygen content were determined. All transfers of the water were made by a siphon immersed under water to avoid bubbles. Analyses were made to complete 24-hour cycles; time is given as Eastern Standard Time. Analyses made according to the standard A.P.H.A. methods.

EFFECT OF SUNLIGHT ON RUNNING STREAMS

The dissolved oxygen determinations obtained in the tidal section of the Delaware River below Trenton, N. J., are given in Figure 1. The dissolved oxygen increased rapidly during the morning hours, with a maximum between noon and 4 p.m. During this period the tide was outgoing, so that the pollution, which is discharged by Trenton and the cities below, had no effect. With the turn of the tide the dissolved oxygen decreased rapidly during the next few hours, with the decrease slowing up when the maximum flood tide approached. During daylight hours the dissolved oxygen increased rapidly with outgoing tide, but during the night with outgoing tide it decreased still further until the lowest was reached at about 3 a.m. As daylight increased the dissolved oxygen increased. The temperature of the water was constant between 8 a.m. and 6 p.m., and in spite of the decrease in temperature the dissolved oxygen decreased rapidly during the night. This is contrary to the solubility of oxygen at

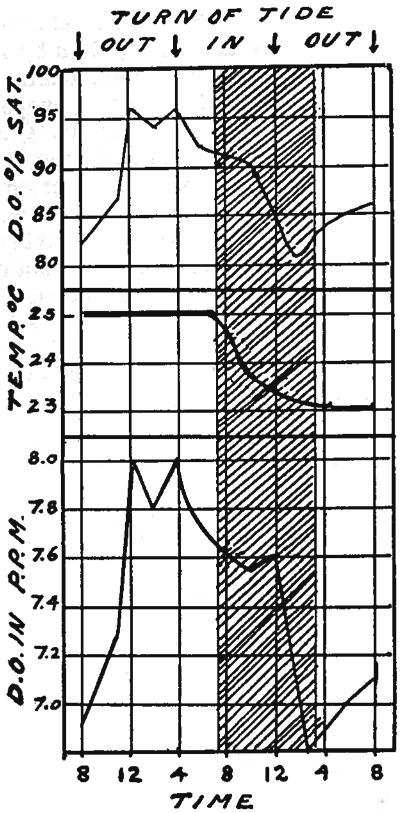

Figure 1 - Dissolved Oxygen in the Tidal Section of Delaware River.

different temperatures; an increase in dissolved oxygen rather than a decrease could be expected. These changes were not peculiar to the water in the tidal section. For example, the results obtained during daylight hours in the river about 50 miles above Trenton (the river is subject to tide up to Trenton) 2 days previous are given in Figure 2. The temperature fluctuation during the day was 1° C. The rapid increase in dissolved oxygen continued until a maximum was reached at 3 p.m. The increase and decrease in saturation occurred irrespective of any small temperature fluctuations. Similar results were obtained in a number of instances, which will be published elsewhere. This paper deals mainly with some of the factors which seem to be responsible for the fluctuations.

A set of results obtained with Delaware River water, brought to the laboratory, is given in Figure 3. The experiment was conducted on August 6, 1929, and the days following. The dissolved oxygen decreased gradually until 3:15 a.m., after which it began to rise slowly but did not reach the original value. The dissolved oxygen was practically constant during the afternoon with a constant temperature, decreased with a rapidly decreasing temperature, followed again by a slow rise in dissolved oxygen in spite of a further decrease in temperature. The decrease of dissolved oxygen at night, in spite of the decreasing temperature, was undoubtedly due to the consumption of oxygen by microorganisms in the process of respiration and decomposition. The rise in dissolved oxygen in the early morning hours before the action of light became effective was probably due to the further decrease in temperature, but the continued rise during the rest of the day must be due to the activities of the green organisms. In this case re-aeration was confined to the green organisms, since wind and rippling of the surface of the water were eliminated.

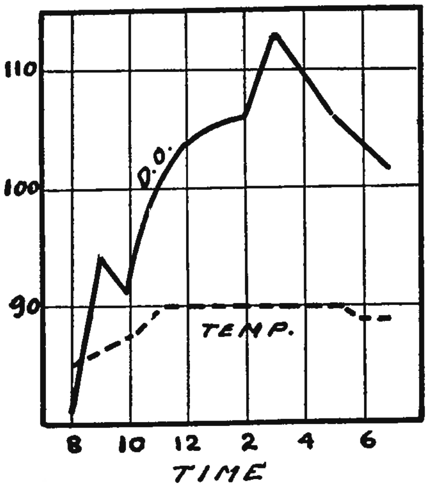

Figure 2 - Dissolved Oxygen during Daylight above Trenton, N. J.

The samples of water were kept in diffused light, and it was thought that the re-aeration due to the organisms might have been more intense if the water was kept in direct sunlight. The samples were exposed for 6 hours to direct sunlight and analyses made at intervals. An exposure of 1-1/2 hours increased the dissolved oxygen from 7.2 to 7.5 p.p.m., while the temperature increased from 20° to 24.5° C. No further increase in dissolved oxygen occurred, but the temperature of the water continued to rise so that the dissolved-oxygen saturation increased from 80 to 93 per cent. Thus the intensity of the light (direct sunlight with higher temperature as compared with light from an overcast sky) did not increase the degree of re-aeration, but hastened the time in which maximum oxygen production was possible.

Two other series of samples were subjected to light and darkness, while another series was kept in the dark. Those exposed to the light increased in dissolved oxygen while the temperature decreased; those kept in the dark decreased gradually in dissolved oxygen. The difference caused by the action of light amounted to 15 per cent.

Other samples were placed in stoppered glass bottles and submerged in water. In these instances no surface aeration could take place and the light had to penetrate not only a depth of 6 inches (15 cm.) of water but also the glass. The results are shown in Figure 4. An increase in dissolved oxygen took place until between 7 and 8 p.m., when a maximum was reached of 9.5 p.p.m. During the afternoon the saturation increased to 112 per cent, decreasing to about 100 per cent at 4:30 a.m. and again increasing to 118 per cent at 11 a.m. In these instances the oxygen liberated could not escape from the bottles, which accounts for the saturated condition even in the early morning hours. The water kept in the dark decreased from 8.4 to 7.5 p.p.m. in a straight line, while the saturation decreased from 101 to 90 per cent as compared with the increase to 118 per cent.

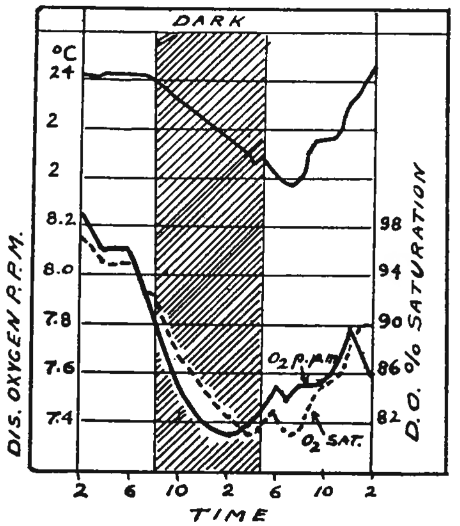

Figure 3 - Dissolved Oxygen in Delaware River Water as Tested in Laboratory.

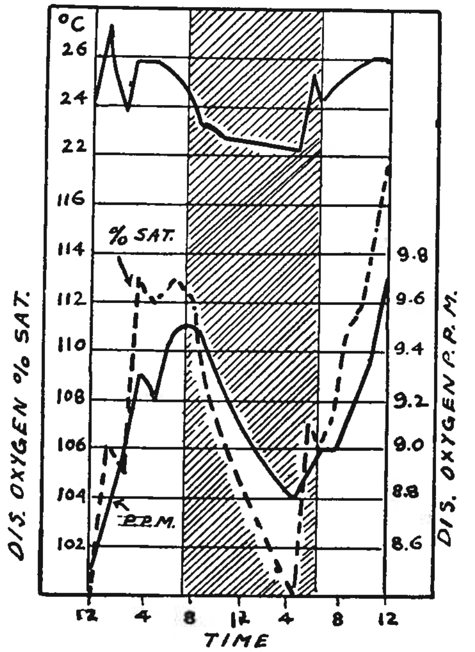

Figure 4 - Dissolved Oxygen in Samples Placed in Stoppered Bottles Submerged in Water.

Experiments made with distilled water to find out whether daily fluctuations took place when exposed to similar conditions in open beakers and stoppered bottles showed that the dissolved oxygen of the water did not increase in the dark and decreased slightly in the light.

The most abundant green organisms were Closterium, Pleurococcus, Eremosphora, Scenedesmus, Protococcus, Raphidium, and Botrycoccus. The number of algae were as high as 5200 per cc.

DIURNAL CHANGES IN WATER CONTAINING GREEN ALGAE

The diurnal changes in dissolved oxygen are similar from day to day, except that the dissolved oxygen may gradually increase. During the summer of 1930 laboratory experiments were conducted in an effort to determine the relation of the number of organisms to the chemical changes taking place.

Large samples of water, densely green with organisms, were collected from a creek tributary to the Delaware, receiving the effluent from some small sewage-disposal plants. The water was placed in carboys and subjected to alternating light and darkness for varying lengths of time.

The dissolved oxygen results of a part of the experiments, together with the changes in pH values, are given in Figure 5. The water when collected had a dissolved-oxygen content of 12.9 p.p.m. or a saturation of 154 per cent. After having been kept for 1 day in semi-darkness, the water was placed in an incubator for 18 hours, then placed in daylight for 10 hours, and so on. The dissolved oxygen dropped during the time the water was kept in semi-darkness from 12.9 to 2.2 p.p.m. and after having been placed in the incubator to 1.2 p.p.m. During the next 7 daylight hours the dissolved oxygen increased to 14.7 p.p.m., decreased again during the night, and rose the following day to 21 p.p.m. Again during the next dark period it dropped to 10.9 p.p.m., from which it rose in 8 hours to 23.8 p.p.m. or a saturation of 282 per cent. The water was then subjected to a prolonged period of darkness of 63 hours, after which time the dissolved oxygen dropped to 3.2 p.p.m. During these periods the temperature was kept constant in the incubator at 21° C. As soon as the water was put back into daylight, the dissolved oxygen increased in 9 hours from 3.2 to 15.4 p.p.m.

The pH values fluctuated directly with the dissolved oxygen as may be seen from Figure 5. They rose by steps from 6.9 to 9.6+, while during the prolonged period of darkness this figure decreased to pH 7.1. The changes in carbon dioxide and carbonates were far less pronounced.

It is evident that the action of light has a cumulative effect, reaching under ordinary conditions its maximum at mid-day or thereafter. It seems to be more a time factor than merely an intensity effect, because the effects were the same when radiation was through glass or on cloudy days.

The numbers of blue-green and green organisms (photosynthetic) in the water were very high and mainly of the following species: Oscillatoria, diatoms (about six genera, particularly filamentous forms), Scenedesmus, and a few Microcytis, Pediastrum, and Desmids. Among the green flagellate protozoa Trachilomonas was most abundant. Most of the organisms were the blue-green Oscillatoria. The photosynthetic organisms slowly decreased during the 8 days of the experiment here reported -- namely, from 45,400 to 32,700 per cc. Bacterial eaters gradually increased.

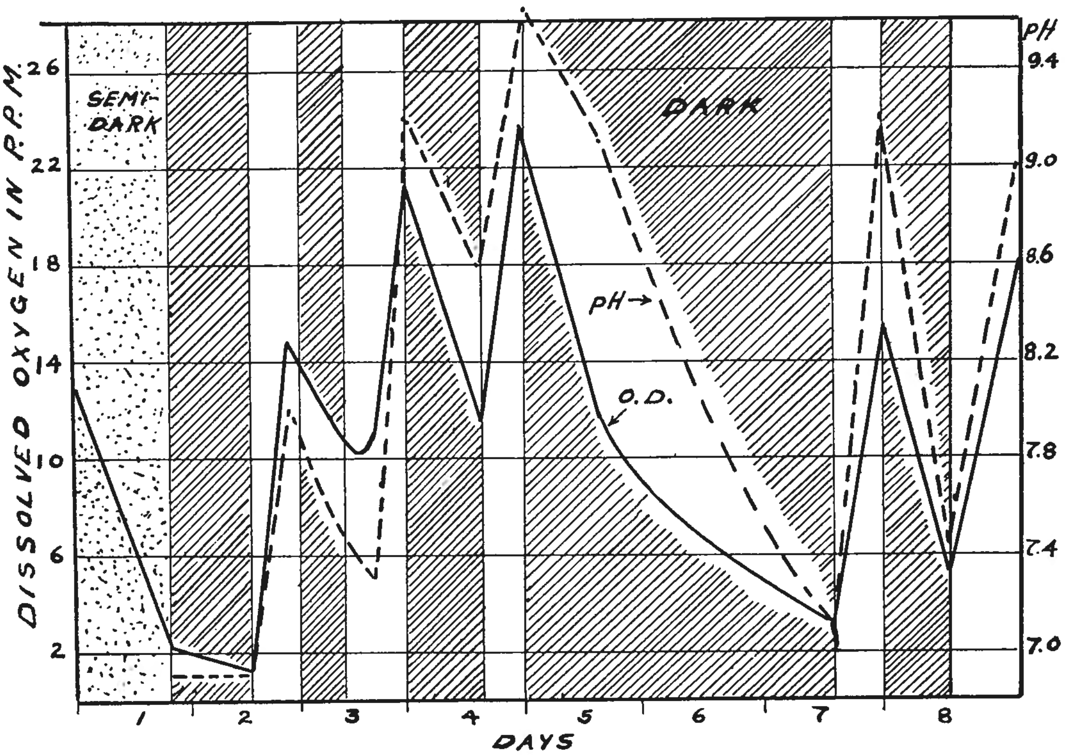

Figure 5 - Changes in Dissolved Oxygen and pH.

EFFECT OF CONCENTRATION OF ORGANISMS

The water with the large number of organisms was diluted by half with a mixture of river and tap water. The effect on the oxygen dissolved in the water was very pronounced, as may be seen from the following figures:

Time	Dissolved Oxygen	
Days	Concentrated P.p.m.	Diluted P.p.m.
1	14.7	10.4
2	21.0	10.0
3	23.8	11.1
6	15.4	7.4

In the "diluted" water there were approximately half as many organisms as in the "concentrated" water, while the dissolved oxygen was also approximately half.

DISCUSSION

In dealing with the pollution of a stream the role of re-aeration by green organisms must be properly evaluated. If the pollution is not excessive so that the production of oxygen is overbalanced by the consumption, a marked increase in dissolved oxygen will result. With a more heavily polluted stream the dissolved oxygen might show from day to day, when samples are taken in the afternoon, complete saturation leading to erroneous conclusions because the temporary condition in the afternoon is by no means the daily average condition. Moreover, these erroneous results are usually obtained in the spring and especially in July and August with low stream-flow conditions and higher temperatures. From the reported and other results obtained it is believed that results for dissolved oxygen have been interpreted as meaning far more than was actually warranted. In stream-pollution surveys several more factors must be taken into consideration. From the high pH values obtained during the afternoons the deduction could have been made that either the water was alkaline or that large quantities of strongly alkaline trade wastes had been discharged.

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THE PLANKTON OF THE SANGAMON RIVER IN THE SUMMER OF 1929

Samuel Eddy

The Sangamon River, a small river in the central part of Illinois, has special interest to students of aquatic biology because it exhibits in a remarkable way the effects of the installation of a sewage treatment plant in alleviating pollution and at the same time the effects of the erection of a dam to impound water for municipal and industrial uses. The present study is an attempt to determine to what extent these effects are reflected by changes in the abundance of certain kinds of microscopic organisms, collectively called plankton, which live suspended in the water. As is well known, some kinds of plankton organisms, if present in sufficient numbers in reservoirs, may give disagreeable flavors to the water; other kinds may aid in the natural purification of polluted waters; and in streams and lakes generally plankton plays a role of more or less importance as food for larger organisms, including fishes. In our larger streams, such as the Rock River and the Illinois River, the plankton may be an important factor in fish production. In the Kaskaskia River, as an example of our smaller streams, the plankton is so scanty that it can have very little importance. The Sangamon River illustrates an intermediate stage in which the plankton is abundant enough to enter into the food chains of fishes to some extent but does not result in a yield of fishes appreciably greater than in the Kaskaskia. The writer's observations of plankton development in the upper part of the Sangamon from 1923 to 1929 were included in a general study on "Fresh-water Plankton Communities," submitted as a thesis in the Graduate School of the University of Illinois but not yet published. Further collections, made during the summer of 1929, showing the variety and abundance of organisms present at selected stations along the lower part of the river as well as the upper part, are reported in this paper.

The Sangamon River rises in McLean County and at first flows eastward into the northwestern part of Champaign County, where it turns southward and passes the villages of Foosland, Fisher, and Mahomet. It then flows in a general southwestward direction across Piatt County, passing Monticello, and across Macon County, passing Decatur. In Sangamon County, it receives its first large tributary, the South Fork, and passes Riverton and Springfield. It flows northward across Menard County, passing Petersburg. At its junction with Salt Creek it turns westward. It continues in a generally westward direction, forming the boundary between Mason County and Cass County, passing the village of Chandlerville, and finally emptying into the Illinois River about ten miles above Beardstown.

The length of the river is about 237 miles. The distance from the source to Decatur is about 103 miles, from Decatur to Springfield about 59 miles, and from Springfield to the mouth about 75 miles. The total drainage area is about 5,390 square miles, of which 1,940 square miles belong to Salt Creek, and 846 square miles belong to South Fork.

The current of the river at normal levels is never very great, since it flows through glacial till and occupies a well-worn valley. The river falls 120 feet in the first 10 miles and 300 feet in the balance of its course, or less than 2 feet per mile. The fall is far from regular, however, and there are many stretches where the gradient is very slight. The bottom is usually sand or fine silt, the latter predominating over most of the river.

Previous to 1923, no obstructions were encountered in the upper course of the river except several small ruined mill-dams. At Decatur a small dam raised the water level a few feet and held back a small supply for municipal purposes. Below this dam the city of Decatur discharged all its sewage, which usually was greater in volume than the water flowing over the dam. During times of low water, the sewage constituted the entire flow of the river below the dam, as all of the water above the dam was then diverted through the city water supply system. As a result of the pollution, the river below Decatur was devoid of normal aquatic life. Jewell (1920) reported no living organisms immediately below Decatur except those accustomed to conditions of pollution. Thirty miles below Decatur conditions were found to be improving, but even at Springfield, almost 60 miles downstream, the normal life was not completely restored. The writer was well acquainted with the river previous to 1920 and clearly remembers the extreme condition of pollution existing for at least 20 miles below Decatur. The bottom was covered with a thick layer of foul sludge, and the opaque water, which varied in color from inky black to milky white, depending on the season, contained large quantities of floating mouldy wastes.

At Springfield a second dam has obstructed the river for many years, raising the level of the water about six feet and forming a narrow pool that extends upstream several miles. Pollution below Springfield has been largely eliminated since the city's sewage treatment plant was put into operation, July 10, 1929. The wastes from Petersburg and Chandlerville are not sufficient to pollute the river to an appreciable extent.

In 1923 the city of Decatur, in order to increase its water supply, completed a large dam across the river just above the site of the old one, creating a lake one-half mile wide and 12 miles long. Later, in 1924, a sewage disposal plant was put into operation, handling one-third of the city wastes, and in 1928 the plant was enlarged to accommodate all the wastes. This relieved the extreme condition of pollution. The dredging of a new channel from Harristown for 20 miles downstream has aided by furnishing a new bed, free from the accumulated bottom sludge. These changes have resulted in a fairly clean stream, flowing through a lake-like reservoir in its upper region.

In the writer's previous study of the plankton of the upper river from 1923 to 1928, inclusive, weekly or semi-monthly collections were made from the river at Decatur and above. Very little plankton was found above Lake Decatur in those years. At Mahomet, about 50 miles from the source, no plankton forms occurred, though bottom organisms, especially diatoms and protozoans, occasionally appeared in the collections. The same was true at Monticello during the greater part of the year, but in mid-summer or early autumn, when the water was low, a scanty population of plankton organisms was found there. This was the first point in the course of the stream where plankton ever appeared. At Rhea's Bridge on the upper end of Lake Decatur, plankton was present in the water during most of the year but was never as abundant as at Lost Bridge, one mile above the dam, where many plankton species were abundant from March until December. During January and February the plankton of the lake was scanty and consisted chiefly of protozoans.

In 1929, trips were made in June, July, and September, for the purpose of collecting samples at intervals of about 20 miles over the entire river. The collections were made from bridges at or near Mahomet, Monticello, Lake Decatur, Harristown, Illiopolis, Riverton, Springfield, Petersburg, and Chandlerville. The method was to dip the water from mid-channel by lowering a ten-liter bucket on a rope. No stratification of plankton was noticed except at Lake Decatur, where the current was negligible and the plankton was much heavier near the surface. The principal collecting station on the lake was at Lost Bridge, and at this station a series of collections was made from bottom to surface and averaged. Each set of collections made at the other stations consisted of a 100-liter silk-net collection and a one-liter collection which was preserved with formalin and allowed to settle and then decanted in order to obtain the nannoplankton. The organisms were counted by the usual method in a Sedgwick-Rafter slide. All data were computed per cubic meter. The volume of the plankton in the silk-net collections was obtained by centrifuging for 3 minutes at 2000 revolutions per minute. The volume of the decanted plankton was not determined because of the large amount of silt present.

At the times of collecting, the river was 1-2 feet deep and 25-40 feet wide at Mahomet, the uppermost station, and 8-10 feet deep and 200-210 feet wide at Chandlerville, the lowermost station. The deepest portion from which collections were made was in Lake Decatur where the depth in the channel ranged from 10 to 18 feet. Below Decatur the river was quite shallow. It was 2-4 feet deep and 60-75 feet wide at the Harristown and Illiopolis bridges. At Riverton, after the union with the South Fork, the river was 4-6 feet deep and 100-114 feet wide. At the bridge north of Springfield the water (backed up by the dam) was 5-7 feet deep and 100-110 feet wide. At Petersburg the river was 100-150 feet wide and 7-10 feet deep in mid-channel.

The current, which was moderate at most places, was very slow in some stretches of the river and somewhat swifter in others with a greater fall. At Mahomet and Monticello, the current averaged about one-half mile per hour during the summer. In the main part of Lake Decatur no current could be detected. At Harristown and Illiopolis the current averaged about one mile per hour; at Riverton one-half mile per hour; and at Springfield just above the dam it was too slow to estimate. At Petersburg and Chandlerville it averaged a little more than one-half mile per hour.

The river level was slightly above normal when the plankton collections were made in June and July. The readings of the gage at the Decatur sewage disposal plant averaged 587.3 feet for June 25-27 and 587.6 feet for July 26-28. April and May were the highest months for the year 1929, the gage at the disposal plant reaching a maximum of 593.5 feet in those months. The lowest stage for the year was in September, although the gage readings on the dates of collections, September 10-12, averaging 584.0 feet, were not the lowest of the month. Thus the river was about 3-1/2 feet lower in September than it was when the June and July collections were made. The Decatur lake, however, did not fluctuate much, as the gage reading above the dam was 610.25 in June and July and 609.95 in September.

The temperature of the water at the time of collecting was about what would be expected under normal summer conditions. In June it ranged from 24° to 25° C. and in July from 25° to 28° C. No temperature data were obtained on the September trip, as the thermometer was broken in the field.

Hydrogen ion determinations were made at all stations and were found to run consistently about pH 7.6. This seemed normal for the river, as the readings agreed with those obtained by the writer in previous observations. On the upper river from 1923 to 1929, the readings in summer always ranged around pH 7.6, dropping to pH 7.0 or lower in winter.

Determinations of dissolved oxygen in the water at each station on the June trip were as follows: Mahomet 4.75 cc. per liter, Monticello 4.06, Decatur 4.62, Harristown 4.06, Illiopolis 4.62, Riverton 4.25, Petersburg 4.25, and Chandlerville 6.47. No determinations can be given for Springfield, as the June collections and data from that station were accidently lost. There was only a slight fluctuation in the amount of dissolved oxygen in the water at the various stations. At all points examined, the supply seemed sufficient for the support of abundant aquatic life.

A summary of the plankton collections is given in Table I, and the constituent organisms are listed in Tables II, III, and IV.

The general taxonomic composition of the plankton found in the river below Monticello was the same as that observed in most shallow lakes and larger streams of North America. Certain typical forms were conspicuous in their proper seasons, namely: two protozoans, Codonella cratera and Ceratium hirundinella; rotifers of the genera Brachionus, Synchaeta, Polyarthra, and Keratella; various cladocerans, particularly Moina affinis, Daphnia longispina, and Bosmina longirostris; and two copepods, Diaptomus siciloides and Cyclops bicuspidatus. A few bottom organisms, usually diatoms and protozoans, were often conspicuous in the plankton collections from the shallow portions of the river where the current could easily sweep them up from the bottom. They did not often appear in the collections from Lake Decatur but were quite common in the collections from the other stations, especially at Monticello, Harristown and Illiopolis.

The collections made in June showed no plankton at Mahomet and only a very scanty plankton at Monticello. The first heavy plankton occurred at Lost Bridge in Lake Decatur. Both the volume of the plankton and the number of species in the collections decreased downstream as far as Petersburg and Chandlerville, where the number of species increased slightly, though the volume of the plankton continued to decrease. Of the 50 species observed in the collections from the entire river in June, 36 appeared in Lake Decatur and 12 appeared farther downstream in relatively small numbers. Evidently a large amount of the downstream plankton owed its origin to the increase in Lake Decatur. Characteristic species which were most conspicuous in Lake Decatur and showed a decrease downstream were Difflugia lobostoma, Codonella cratera, Brachionus angularis, Polyarthra trigla, Keratella cochlearis, Moina affinis, Daphnia longispina, Bosmina longirostris, Cyclops bicuspidatus, and Lysigonium (Melosira) granulatum. Several other members of the plankton conspicuous in the lake did not appear at all below. The flagellates, Trachelomonas volvocina and Euglena viridis, decreased downstream to Petersburg and then started to increase. The only form that showed a decided increase below the lake was one of the algae, Actinastrum hantzschi.

The collections made in July showed that the plankton then had a distribution very similar to that of the preceding month. At Mahomet there was no plankton at all, and at Monticello it was very scanty. Of the 58 species found in the July collections, 47 first became abundant in Lake Decatur. Only 8 species occurred downstream which did not occur in the lake, and these were usually rare or inconspicuous, never forming an important part of the plankton. Many forms which were conspicuous in Lake Decatur showed a decided decrease below Decatur and apparently had their origin in the lake. Examples of these were the following: Pandorina morum, Pleodorina illinoisensis, Codonella cratera, Difflugia lobostoma, Trachelomonas ensifera, Euglena viridis, Ceratium hirundinella, Eudorina elegans, three species of the genus Brachionus and species of Filinia (Triarthra), Asplanchna, Polyarthra, Synchaeta, Pedalia, and Trichocerca (Rattulus), and Lysigonium (Melosira) granulatum. Only a few forms which decreased below Decatur showed a slight increase at Chandlerville. A peculiar feature was an increase in the number of Cyclops bicuspidatus, Keratella cochlearis, Diaphanosoma brachyurum, and Brachionus angularis at Harristown and Illiopolis. In general, the July plankton showed a decided decrease below Decatur. Just as in June, the lake apparently was acting as a reservoir, developing an abundant plankton which was then carried downstream and gradually thinned out in the lower river as the water was diluted by tributaries.

The September collections were made under somewhat different conditions from those in June and July, for the level of Lake Decatur was slightly below the crest of the dam, so that little or no water passed over, and the chief source of the water in the river below Decatur was the effluent from the city's sewage disposal plant. The current in the river was not as swift as at higher river levels, and under such conditions the larger tributaries, particularly the South Fork and Salt Creek, might be expected to add a small amount of plankton. While there still were no plankton organisms found at Mahomet, the plankton was more abundant at Monticello than previously. In Lake Decatur the collections were found to have a somewhat smaller volume and to include fewer species than previously. Downstream from the lake, however, many species, apparently originating in it, especially protozoans and algae, showed a steady increase in abundance; and several species additional to the lake list make their first appearance just below Decatur. Many conspicuous members of the plankton, particularly rotifers, appeared first at Riverton after the union with the South Fork and were abundant downstream from there. A decided increase in both abundance and species was noted at Springfield, which may in part be due to slack water above the dam. A further increase at Petersburg indicated that other conditions were favorable for greater plankton production.

Only a few species abundant in Lake Decatur showed a tendency to decrease rather than increase downstream. These were Difflugia lobostoma, Codonella cratera, Brachionus angularis, Keratella cochlearis, and some of the cladocerans and copepods. Of the 66 species found in the September collections, only 25 occurred in Lake Decatur, and 33 species occurred in the downstream collections which did not appear in the lake. Many of the latter showed a tendency to increase downstream. The increase was marked at Springfield and Petersburg, indicating that the lower river was maintaining a plankton population due in part to the low water stage and the reduction of the current. Such conditions in the river approach lake conditions, the waters remaining longer in the pool-like stretches. Since no water was then coming directly downstream from the lake, all the water in the river was effluent from the sewage disposal plant. Agersborg (1929) found this effluent to be teeming with annelids, rotifers, copepods, protozoans and algae, and states that these are organisms such as live in small ponds, though failing to mention any species which are typical of either clean-water or sewage plankton. It is doubtful if many, or any at all, of the lake forms survive passage through the sewage disposal plant, comprising as it does both sand filters, tanks and Dorr separators; and still more doubtful that there is any important development of additional plankton species until after the passage through the plant is completed.

Sphaerotilus natans, although very abundant in the sewage disposal plant, did not appear at any time in the collections. It is probable that the origin of many of the downstream plankton species at this period was in the quieter stretches of the river, which were seeded by the plankton originating in the lake at times when the water was passing over the dam.

The question often arises whether the plankton in a given part of a stream is developed there under local conditions or whether it is carried down from upstream. This survey indicates that, at times, part of the plankton, at least, is carried downstream. Wiebe (1928) and the Minnesota State Board of Health (1928) show that clean plankton from upstream is carried through polluted areas in the Mississippi below Minneapolis and St. Paul. In the Sangamon the downstream decrease observed in June and July may be due partly to the fact that local development was not sufficient to counterbalance the dilution from tributaries. In September, when the low stage of the water cut off the direct supply from the lake, local conditions downstream became more favorable for the development of plankton. When the current becomes very slow, the development of plankton becomes local and is governed by local conditions. If the current averaged one-half mile per hour, the time required for water to flow from the source to the mouth would be about 20 days. However, at normal stages the river has many pool-like stretches which retard part of the water, and rough estimates of the period of detention in the lake at Decatur range from two weeks to two months, depending on the river level. Thus the water remains in the lake at least twice as long as in the rest of the river. The water and the plankton it bears as it flows over the dam at Decatur will ordinarily be in the neighborhood of Chandlerville about a week later. In this way, at normal levels, there is a continual stream of water carrying plankton from the lake and passing downstream. Even though the downstream conditions are not favorable for plankton development, it seems possible for the water to retain part of the original plankton load for a week or more, so that a series of collections made at various points in the lower course of the river do not represent the development of plankton at each point but give glimpses of various stages of senescence as the plankton moves away from its source. It may be possible that the plankton observed downstream in September had originated from the lake when the water was still flowing over the dam, and that it was still progressing downstream. This, however, would hardly explain the origin of the plankton observed in the river immediately below Decatur.

No evidence of the former pollution was observed in the plankton of the Sangamon River. No pollutional organisms were found at Harristown, about eight miles below Decatur, where Jewell ten years earlier had found the plankton to be characterized by Sphaerotilus natans, nematodes, ciliates, and creeping rotifers, with desmids and phytoflagellates common when the water was high. In this area in 1929 the plankton was typical of clean water and was characterized by Codonella cratera, Polyarthra trigla, rotifers of the genus Brachionus, Cyclops bicuspidatus, cladocerans, and Lysigonium (Melosira) granulatum. Jewell found the dissolved oxygen usually low in that part of the river, especially during periods of low water. The determinations of dissolved oxygen made in 1929 showed an abundant supply. The sludge which was formerly so abundant had nearly disappeared, the water was clear, and a number of fishes were observed.

Very little is known regarding the former condition of the plankton below the polluted part of the river. Jewell's studies in 1918-1919, which extended only as far as Springfield, showed that the influence of pollution had partly ceased there and that a few typical clean-water plankton organisms were present in the river at that point. The abundant clean-water plankton now found in that part of the stream, including many more species than were reported by Jewell, indicates that the plankton population in the lower river is much greater than formerly, and this is due, no doubt, to the creation of the lake at Decatur and to the removal of the pollution barrier.

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TABLE I.

SUMMARY OF PLANKTON COLLECTIONS, SANGAMON RIVER, 1929.

Station	Volume (cc. per cubic meter)			Number of species represented		
	June 25-27	July 26-28	Sept. 10-12	June 25-27	July 26-28	Sept. 10-12
Monticello..........	.08	.08	.05	9	8	16
Lake Decatur.......	15.20	9.50	9.60	36	47	25
Harristown.........	6.00	8.00	10.00	22	34	27
Illiopolis............	9.00	8.00	8.40	23	31	26
Riverton............	3.00	3.90	3.60	17	35	35
Springfield..........	....	.80	12.60	..	28	36
Petersburg..........	2.20	.40	17.00	22	22	39
Chandlerville.......	.50	.30	6.00	24	22	30

TABLE II.

NUMBERS OF PLANKTON ORGANISMS PER CUBIC METER IN THE SANGAMON RIVER, JUNE 25-27, 1929.

Italics indicate decantation collections.

Organisms	Monticello	Lake Decatur	Harristown	Illiopolis	Riverton	Petersburg	Chandler-ville
PROTOZOA							
Difflugia lobostoma Leidy	*86,820*	*100,000*	*86,658*	*60,000*	*25,000*	*22,000*	*20,000*
Trachelomonas ensifera Daday	*43,000*						*888,000*
Euglena sp.	*40,000*	*50,000*					*660,000*
Codonella cratera (Leidy)	*42,000*	*6,000,000*	*288,860*	*280,000*	*290,000*	*440,000*	*60,000*
Tintinnidium fluviatile Stein		*750,000*			*14,000*	*11,500*	*220,000*
Phacus longicaudus (Ehr.)		500		580		400	
Ceratium hirundinella O.F.M.		1,000					2,500
Euglena oxyuris Schmarda		*50,000*		1,100		800	
Trachelomonas volvocina Ehr.		*50,000*	*28,850*	*27,000*	*28,000*	*20,000*	*84,000*
Euglena viridis Ehr.		*100,000*	*28,000*	*55,000*	*16,000*	*22,200*	*110,000*
Dinobryon sertularia Ehr.		15,000	15,000	11,600			250
Centropyxis aculeata Stein			2,000	2,200	1,000	1,600	
Arcella vulgaris Ehr.			*25,000*	*28,000*	550	800	
Trachelomonas hispida (Perty)				*25,000*			
Pleodorina illinoisensis Kofoid					510		250
Eudorina elegans Ehr.						2,400	500
Euglena acus Ehr.							120
Pandorina morum Bory							*110,000*
ROTATORIA							
Filinia longiseta (Ehr.)	240	10,000					
Brachionus angularis Gosse	200	10,000	500	580	500	700	2,500
Brachionus capsuliflorus Pallas		3,000					
Brachionus calyciflorus Pallas		1,500					
Brachionus budapestinensis Daday		15,000				400	
Synchaeta pectinata Ehr.		500				1,200	
Brachionus patulus O.F.M.		500					
Asplanchna sp.		15,000					500
Polyarthra trigla Ehr.		90,000	15,000	8,700	1,100	12,000	1,000

TABLE II—Concluded.

NUMBERS OF PLANKTON ORGANISMS PER CUBIC METER IN THE SANGAMON RIVER, JUNE 25-27, 1929.

Italics indicate decantation collections.

Organisms	Monticello	Lake Decatur	Harristown	Illiopolis	Riverton	Petersburg	Chandler-ville
Keratella cochlearis (Gosse)		50,000	2,500	1,200	1,080	8,000	3,700
Lecane spinifera (Western)		1,000					
Rotaria neptunia (Ehr.)		250					250
Pedalis mira (Hudson)			1,000				
CLADOCERA							
Moina affinis Birge		30,000	500				
Diaphanosoma brachyurum (Liéven)		2,500	15,000	2,000			
Daphnia longispina (O.F.M.)		15,000	1,000	1,100			
Bosmina longirostris (O.F.M.)		10,000	1,000	5,800			2,500
Scapholeberis mucronata (O.F.M.)		500					
Chydorus sphaericus (O.F.M.)		500					
COPEPODA							
Cyclops bicuspidatus Claus		75,000	25,000	47,200	540		1,000
Cyclops viridis Jurine	240						
Immature copepods		150,000	190,000	92,000	2,700	12,000	5,000
ALGAE							
Undetermined diatoms	*1,736,460*	*2,500,000*	*2,880,000*	*1,728,000*	*1,300,000*	*1,200,000*	*1,110,000*
Gyrosigma spp.	*43,411*	*50,000*	*25,000*				
Lysigonium granulatum (Ehr.)		*25,000,000*	*8,665,800*	*2,800,000*	*1,450,000*	*1,334,000*	*2,220,000*
Closterium acutum (Lyngb.)		*50,000*					
Coelastrum microporum (Nägel)		*40,000*					*22,000*
Ankistrodesmus falcatus (Corda)		*60,000*	*288,860*	*884,000*	*56,000*		
Actinastrum hantzschi Lager		*35,000*					*21,200*
Scenedesmus quadricauda (Turp.)			*28,000*	*58,000*		*22,000*	
Pediastrum duplex Meyen			1,000	5,800	5,400	2,000	
Scenedesmus dimorphus (Turp.)				*26,000*	*28,000*	800	
Synedra tenuissima Kützs						2,400	

TABLE III.

NUMBERS OF PLANKTON ORGANISMS PER CUBIC METER IN THE SANGAMON RIVER, JULY 26-28, 1929.

Italics indicate decantation collections.

Organisms	Monticello	Lake Decatur	Harristown	Illiopolis	Riverton	Springfield	Petersburg	Chandlerville
PROTOZOA								
Difflugia acuminata Ehr.	*15,000*					800		
Pandorina morum Bory		*400,000*			*187,200*	*24,000*	*25,500*	*69,600*
Platydorina caudata Kofoid		75,000			220			
Pleodorina illinoisensis Kofoid		125,000	660		880			
Codonella cratera (Leidy)		*1,600,000*	*490,000*	*966,000*	*1,248,000*	*1,470,000*	*357,000*	*70,000*
Difflugia lobostoma Leidy		*650,000*	*98,000*	*644,000*	*624,000*	*26,000*	*51,000*	1,260
Trachelomonas ensifera Daday		*220,000*		*32,200*	*62,000*	*73,500*	*12,000*	*70,000*
Trachelomonas hispida (Perty)		7,500			*30,000*			
Phacus longicaudus (Ehr.)		250					220	420
Euglena viridis Ehr.		*210,000*	*95,000*		*125,000*	*98,000*	*76,500*	*139,200*
Euglena acutissima Lemm.		750						*46,500*
Ceratium hirundinella O.F.M.		8,700	650	7,100	1,320			2,520
Phacus pleuronectes (O.F.M.)		250						
Tintinnidium fluviatile Stein		*120,000*	*25,500*	*30,000*	*60,000*	*122,500*	*51,000*	*140,000*
Eudorina elegans Ehr.		*410,000*		*32,000*	*31,000*	*12,000*		*70,000*
Euglena oxyuris Schmarda		*21,000*		*32,000*	*30,000*			*11,000*
Dinobryon sertularia Ehr.		12,500	19,800	5,400				
Trachelomonas volvocina Ehr.		*30,000*	*49,000*		*62,000*	*245,000*	*76,500*	
Centropyxis aculeata Stein			600	2,160	850	400	440	
Arcella vulgaris Ehr.				4,320				
Gonium pectorale O.F.M.					220			

TABLE III—Continued.

NUMBERS OF PLANKTON ORGANISMS PER CUBIC METER IN THE SANGAMON RIVER, JULY 26-28, 1929.

Italics indicate decantation collections.

Organisms	Monticello	Lake Decatur	Harristown	Illiopolis	Riverton	Springfield	Petersburg	Chandlerville
ROTATORIA								
Brachionus calyciflorus Pallas	260	112,500	28,400	48,600	400			
Brachionus capsuliflorus Pallas		5,000	650	540	1,200	400	220	
Brachionus budapestinensis Daday		187,500	6,600	32,400	890	400		
Brachionus angularis Gosse		10,000	13,200	21,600		1,600	440	
Trichocerca pusilla (Jennings)		5,000	660	550				
Filinia longiseta (Ehr.)		62,500	9,900	37,800	13,200	6,000		1,260
Trichocerca gracilis (Gosse)		12,500		5,400	1,300	800	400	
Asplanchna sp.		70,000	1,980	16,200	880	400		
Polyarthra trigla Ehr.		75,000	33,000	64,800	4,400	450	1,320	1,300
Keratella cochlearis (Gosse)		2,500	13,200	81,000	35,200	8,000	8,800	12,600
Synchaeta pectinata (Ehr.)		225,000	2,640	2,700	2,200	2,000	450	
Pedalia mira (Hudson)		87,500	27,000	43,200	1,760			
Brachionus patulus O.F.M.		250		270				420
Diurella stylata Eyferth		250						
Conochiloides natans (Seligo)		250		1,620				
Schizocerca diversicornis Daday								
CLADOCERA								
Diaphanosoma brachyurum (Liéven)	250	9,900	2,700					
Moina affinis Birge	500	650	540					
Daphnia longispina (O.F.M.)		660	540					
Bosmina longirostris (O.F.M.)		650						

TABLE III—Concluded.

NUMBERS OF PLANKTON ORGANISMS PER CUBIC METER IN THE SANGAMON RIVER, JULY 26-28, 1929.

Italics indicate decantation collections.

Organisms	Monti-cello	Lake Decatur	Harris-town	Illiopolis	Riverton	Spring-field	Peters-burg	Chandler-ville
COPEPODA								
Cyclops bicuspidatus Claus		5,500	5,200	5,400	880	800	880	3,800
Diaptomus siciloides Lillje		120	650	550	440			
Immature copepods	260	37,500	19,800	5,500	2,200	800	880	25,200
ALGAE								
Undetermined Diatoms	*936,000*	*5,000*	*735,000*	*322,000*	*1,560,000*	*490,000*	*25,000*	*3,480,000*
Gyrosigma sp.	*15,500*		*980,000*	1,620	450	*24,500*		
Closterium acutum (Lyngb.)	250							
Lysigonium granulatum (Ehr.)		*10,000,000*	*4,900,000*	*644,000*	*1,872,000*	*49,000*	*127,500*	*139,200*
Scenedesmus quadricauda (Turp.)		*40,000*			*31,200*	*24,000*		
Scenedesmus dimorphus (Turp.)		*20,000*	*25,500*			*23,000*	*25,500*	
Pediastrum duplex Meyen		2,500			870	1,600	440	2,520
Synedra tenuissima Kützt		12,500	*980,000*	2,160	880	2,400	880	
Pediastrum simplex Meyen		240						
Actinastrum hantzschi Lager		*20,000*	*24,000*	*32,000*	*30,000*	*24,500*	*26,000*	*70,000*
Coelastrum microporum Nägel		230						
Surirella robusta Ehr			650					
Sphinctocystis librilis (Ehr.)					*31,000*			
Closterium moniliferum (Bory)								1,260
Aphanocapsa sp.								1,300

TABLE IV.

NUMBERS OF PLANKTON ORGANISMS PER CUBIC METER IN THE SANGAMON RIVER, SEPTEMBER 10-12, 1929.

Italics indicate decantation collections.

Organisms	Monti-cello	Lake Decatur	Harris-town	Illiopolis	Riverton	Spring-field	Peters-burg	Chandler-ville
PROTOZOA								
Difflugia acuminata Ehr.	250		*27,000*	1620	920	500		
Eudorina elegans Ehr.	250	220					480	5,600
Ceratium hirundinella O.F.M.	250	880						
Euglena viridis Ehr.	*62,000*	*1,222,100*	*1,310,000*	*1,400,000*	*97,600*	*1,385,000*	*400,000*	*534,000*
Pleodorina illinoisensis Kofoid		200				500		
Euglena oxyuris Schmarda		*60,000*	*30,000*	*35,000*	*24,000*		*160,000*	
Difflugia lobostoma Leidy		*288,000*	*32,000*	*12,000*	*25,000*	*28,000*	*20,000*	
Codonella cratera (Leidy)		*489,000*	*27,000*	*14,000*	*10,000*	*27,000*	*40,000*	2,800
Phacus longicaudus (Ehr.)		*24,400*	*14,000*	540	1,380	500	1,920	
Trachelomonas hispida (Perty)		440	*27,700*			*2,770,000*	*1,600,000*	
Chlamydomonas spp.		*488,840*				*6,925,000*		
Arcella vulgaris Ehr.			*28,000*	5,500	3,060	5,000		280
Centropyxis aculeata Stein			480	1,080				
Trachelomonas volvocina Ehr.			*1,668,000*	*1,750,000*	*1,220,000*	*48,475,000*	*6,400,000*	*2,670,000*
Phacus acuminata Stokes			*13,000*				*34,000*	
Trachelomonas ensifera Daday				*70,000*	*25,000*	*1,385,000*	*4,000,000*	
Phacus pleuronectes (O.F.M.)				250		500		
Euglena acutissima Lemm.				*70,000*	*20,000*		*80,000*	
Glenodinium sp.					*45,000*	*28,000*	*75,000*	
Tintinnidium fluviatile Stein					*976,000*	*21,930,000*	*4,000,000*	*26,700*
Pandorina morum Bory					*24,400*		480	
Gonium pectorale O.F.M.						*14,000*		
Platydorina caudata Kofoid							2,880	

TABLE IV—Continued.

NUMBERS OF PLANKTON ORGANISMS PER CUBIC METER IN THE SANGAMON RIVER, SEPTEMBER 10-12, 1929.

Italics indicate decantation collections.

Organisms	Monticello	Lake Decatur	Harristown	Illiopolis	Riverton	Springfield	Petersburg	Chandlerville
ROTATORIA								
Brachionus angularis Gosse	250	2,640	240				960	1,400
Brachionus budapestinensis Daday	250							560
Brachionus calyciflorus Pallas	250	850			1,840	375,000	196,800	67,200
Distylla spinifera Western	250				1,600			
Polyarthra trigla Ehr.	250	8,800	480		500	15,000	1,920	1,400
Synchaeta pectinata (Ehr.)	250				980		9,600	
Asplanchna sp.	120						950	
Keratella cochlearis (Gosse)		860	480		230			
Brachionus capsuliflorus Pallas				250	9,200	80,000	2,400	2,800
Synchaeta stylata Wierz.					13,800	1,050,000	384,000	8,400
Trichotria tetractis (Ehr.)					5,060			
Diurella stylata Eyferth						500		
Trichocerca pusilla (Jennings)						5,000		
Trichocerca gracilis (Gosse)						10,000		
Asplanchna sp.						1,000		2,100
Rotaria neptunia (Ehr.)							480	
Trichocerca stylata (Gosse)							450	
Annureopsis fissa (Gosse)								270
CLADOCERA								
Diaphanosoma brachyurum (Liéven)		450						
Daphnia longispina (O.F.M.)		4,500						

TABLE IV—Concluded.

NUMBERS OF PLANKTON ORGANISMS PER CUBIC METER IN THE SANGAMON RIVER, SEPTEMBER 10-12, 1929.

Italics indicate decantation collections.

Organisms	Monticello	Lake Decatur	Harristown	Illiopolis	Riverton	Springfield	Petersburg	Chandlerville
COPEPODA								
Diaptomus siciloides Lillje		6,600	4,800	600	250			
Cyclops viridis Jurine	110	450						
Immature copepods		52,800	9,600	1,200	50	500	900	2,900
ALGAE								
Undetermined diatoms	*3,120,000*	*1,222,100*	*55,550,000*	*35,000,000*	*3,660,000*	*11,080,000*	*10,000,000*	*53,400,000*
Gyrosigma spp.	*936,000*		*277,750*	*350,000*	*732,000*	*28,000*	*160,000*	*1,602,000*
Sphinctocystis librilis (Ehr.)	*15,000*		960					550
Schroederia setigera (Schröder)	*31,200*							
Cyclotella spp.		*2,444,200*				*27,700,000*		*26,700,000*
Pediastrum duplex Meyen		440	7,200	16,200	9,200	45,000	192,000	56,000
Lysigonium granulatum (Ehr.)		*3,660,300*	*22,220,000*	*17,500,000*	*244,000*	*11,080,000*	*4,000,000*	*1,335,000*
Scenedesmus quadricauda (Turp.)		2,200	*111,100*	*1,050,000*	*122,000*	*1,662,000*	*9,600,000*	*2,136,000*
Closterium acutum (Lyngb.)		*122,000*	*277,750*	*350,000*	*24,000*	*13,000*	*800,000*	*276,000*
Selenastrum gracile Reinsch		220						
Closterium acerosum (Schrank)			960				480	
Closterium moniliferum (Bory)			480					540
Ankistrodesmus falcatus (Corda)			*84,713,750*	*14,000,000*	*45,000*	*554,000*	*800,000*	*1,602,000*
Scenedesmus dimorphus (Turp.)			*55,550*	*35,000*	*46,000*	*210,000*	*800,000*	*560,000*
Synedra tenuissima Kütz			*416,625*	*700,000*	*125,000*	*1,108,000*	*70,000*	*534,000*
Coelastrum microporum Nägel				*10,000*	*12,000*	*25,000*	*75,000*	*26,000*
Cosmarium sp.				*10,800*	1,820			
Actinastrum hantzschi Lager				*700,000*	*24,000*	*12,465,000*	*3,200,000*	*1,835,000*
Micratinium pusillum							1,440	5600
Surirella robusta Ehr.					4,600			
Pediastrum simplex Meyen							450	

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AQUATIC LIFE IN WATERS POLLUTED BY ACID MINE WASTE*

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A visitor to coal mining regions for the first time usually remarks the colored water of the streams or strip pits there. Clear red or copper colored, they are much more attractive, from an aesthetic viewpoint, than the black or milky waters produced by industrial or domestic pollution in densely populated areas.

Such copper colored waters, however, represent an extreme of industrial pollution. Coal seams contain sulfur, which, when exposed to air, oxidizes in the presence of water, and so the streams or strip pits have a very high sulfuric acid content; pH values as low as 1.8, representing 35,000 p.p.m. of acid, have been noted. Such acidities are very damaging; water works superintendents or industrial engineers needing boiler water find mine water almost useless; cattle will not drink it, and fish and most plants are quickly killed by it.

These mine runs and pits also represent an environmental extreme. Extreme environments, however, often have their inhabitants, and such is the case with the acid mine waters. One of the higher plants, the cattail, Typha latifolia, grows well in the most acid waters; and several insects, such as Chironomous, the bloodworm, caddis flies, mosquitoes, and a few beetles thrive therein. The most abundant population, however, consists of protozoa and algae, unless the bacteria, insufficiently investigated, might be more abundant.

In the past year more than 200 mine runs or pits have been personally visited and samples taken therefrom to determine their microscopic flora and fauna. The general features were noted of each location visited, the pH was determined, and, if the water was acid, a sampling station was selected which showed some pooling, if in a stream, and with an accumulation of debris in which small organisms might find lodgment. Early samples showed that suspended forms were extremely rare, and an effort was thereafter made to get those forms which might crawl or burrow into debris and bottom films. Samples taken from such situations also tended to include swimming forms, because they had been taken in still water. In April and October 1938, West Virginia mine streams and Indiana strip pits were sampled. In general, the temperatures of mine streams tend to approximate 21° C. on issuing from the mines, for mine temperatures are fairly uniform throughout the year. Strip pits, of course, tend to conform to atmospheric temperatures. Frequently, two samples were taken -- one as close to the mine mouth as possible, yet at a sufficient distance to have been seeded by surface run-off, and another from the same stream or the stream system several miles below. These two samples thus afforded opportunity to show whether animals and plants gradually invaded the stream or strip pits as acidity decreased, and also tended to show how extensive a seeding was necessary to establish life in such waters. The pH of nearby pools, streams, and swamps, not polluted by mine wastes, was determined and their flora and fauna were listed for comparison. By examining widely separated points, it was ascertained that the paucity of living species was not a local condition, but was general for acid mine waters.

Field examination of mine streams in the Spring (1) indicated abundant growths of some algae. Most usual was a green coating along banks, on debris, on rocks in the swiftest currents, and even on vertical moist rock faces. A thin brown coating was also evident at times. A heavy white growth which was common usually proved to be bacterial zooglea. Fungi were scarce, rarely forming extensive growths.

Nonbacterial microscopic organisms were composed principally of protozoa, algae, and rotifers. Table 1 shows the distribution in the plant and animal kingdoms of species found in the samples within the pH range 1.8 to 3.9. All of the commonly occurring ones were identified, but perhaps an additional 10 percent of rarely occurring species could not be recognized. Some identifications may be questionable, especially of very small forms such as the smaller chlamydomonads, which might be zoospores of Stichococcus or Ulothrix. Species definitions had to be based on rather hurried determination of morphological characters, but were usually satisfactory.

A total of 99 species of plants and animals was found living at or below pH 3.9, 85 or which were microscopic types, 76 being algae or protozoa; but the list of commonly occurring microscopic forms included only 17 species. Figure 1 shows the percentage of occurrence in all samples in which these 17 species were found. An organism was arbitrarily termed "common" if it appeared in 15 percent of the samples, "tolerant" if it appeared in 5 percent of the samples, and "adventitious" if it appeared in less than that number. This

* Presented at meeting of the Limnological Society of America, Richmond, Va., December 27-31, 1938.

TABLE 1.—*Distribution of recognized genera and species of plants and animals occurring at or below pH 3.9*

Plants	Number of species	Animals	Number of species
Thallophyta:		Protozoa:	
Fungi	2	Mastigophora:	
Algae:		Euglenidae	7
Myxophyceae	3	Protomastigina	7
Chrysophyceae:		Sarcodina:	
Chrysomonadales	3	Rhizopoda	15
Chrysotrichales	1	Heliozoa	2
Bacillarieae:		Infusoria:	
Pennales	5	Ciliata	19
Chlorophyceae:		Trochelminthes:	
Volvocales	1	Rotatoria	6
Ulotrichales	2	Gastrotricha	1
Chlorococcales	1	Nemathelminthes:	
Zynematales	6	Nematoda	1
Dinophyceae	2	Arthropoda:	
Bryophyta	1	Crustacea:	
Pteridophyta	1	Isopoda	1
Spermatophyta	1	Copepoda	1
		Arachnida:	
		Tardigrada	1
		Insecta	8
		Amphibia	1

Table 1 - Distribution of recognized genera and species of plants and animals occurring at or below pH 3.9.

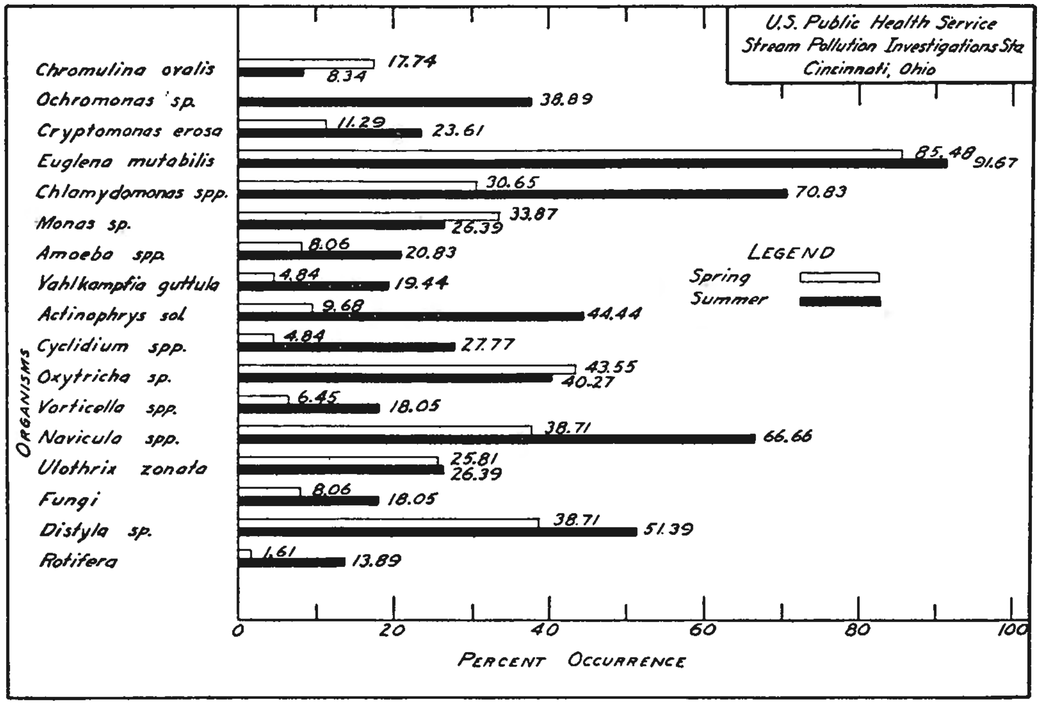


Figure 1 - Percentage of occurrence of the 17 most common organisms in all samples.

arbitrary classification is, of course, open to criticisim, but it serves as a working basis. One of its worst features is that occasionally an organism might be found in but a single sample, yet occur in such large numbers in that sample as to leave no doubt of its tolerance for that particular environmental niche. As an example of this might be mentioned the large numbers of Lepocinclis ovum which were present in Crab Orchard Creek (pH 2.5), where it was the dominant one of six species of microorganisms; or the large number of Raphidiophrys pallida in Riverdale (pH 3.0). Both of these would normally be listed as adventitious forms, but in the particular samples under consideration they were decidedly not. Amoeba radiosa is also listed as an adventitious form, but in laboratory cultures of this mine water it may attain large numbers.

Because of the seasonal differences between the first and last sampling periods (early spring and late summer, respectively), considerable differences in the flora and fauna were anticipated. Actually, very little difference was found. Ochromonas sp., common in later summer, was not found in spring, and the same is true for the small amoeba, Vahlkampfia guttula. Chromulina ovalis, common in spring, was found in 11 of the early samples and in only 6 of the later ones. Frequently, however, it was found impossible to distinguish between this creature and Ochromonas, and it seems probable that some of those listed as Chromulina in the spring samples were Ochromonas. The 17 varieties of common forms appeared in more samples in the late summer, except for Pleuromonas jaculans and Urotricha farcta. Even for the adventitious species the two sets of samples showed largely the same forms, the greatest difference being among the ciliates and rhizopods.

Nor can the species which were encountered be termed rare. Euglena mutabilis (Fig. 2) is far from common unless in an acid situation, but has been recorded by the writer (2) 11 times in 165 samples over a period of several years, while Prof. W. J. Kostir (3), of Ohio State University, has maintained a pure culture of it over a long period. Neither the Chromulina (Figs. 3, 4) nor the Ochromonas (Fig. 5) fit exactly into those species given by Pascher and Lemmermann (4), but they hardly exhibit sufficient differences to be called new species. Three of the ciliates, Chilodonella, Cinetochilum, and Glaucoma, have been shown elsewhere (2) to tolerate wide differences of environment. Probably it is just such species, i.e., those with a wide tolerance, which we might expect to find in these acid waters. The condition has been created largely by man and is, therefore, relatively recent; such

AQUATIC LIFE IN ACID WATERS

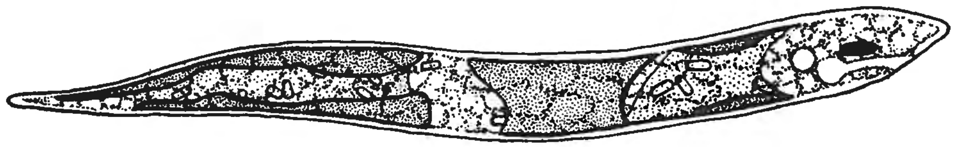
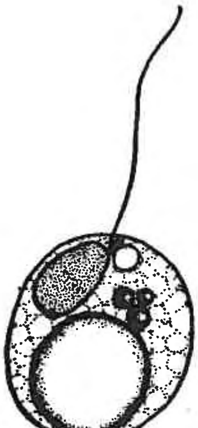
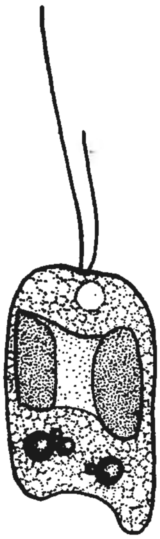
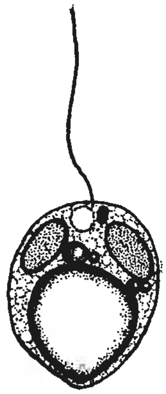


Figure 2 - Euglena mutabilis, showing two or three heavy chloroplastids, conspicuous stigma, small rod-like paramylum bodies, and apparent absence of flagellum.
like paramylum bodies, and apparent absence of flagellum.







Figures 3 and 4 - Chromulina sp., showing one or two chromatophores, stigma, and large posterior granula.
Figure 5 - Ochromonas sp., showing band-like chromatophore and absence of stigma.

species as could occupy the environment have done so, but few, if any, new ones have developed. The absence of acid-tolerant forms is marked for the desmids and shelled rhizopods of bog habitats; but we are dealing here with higher acidities than those of bogs and with a mineral acidity rather than organic acidity.

There is a very large difference between the total number of species found in one of these highly acid samples and in a sample from a stream of stagnant pool or strip pit immediately adjacent to the mine water sample, but whose pH is near neutrality. Any mine water sample could be repeatedly examined with great care day after day and never show more than a few species of microorganisms. Figure 6 shows the average number of species per sample at observed pH values up to and including 3.9. Between pH 3.9 and 4.8 very few samples were obtained; but at 4.8 and above, the number of species which could be counted increased greatly. Thus, 15 samples from pH 4.8 to 7.2, secured for comparison in the early spring trip to the mine fields, showed an average number of 23 microscopic species per sample, and the notation was made for each of these samples: "A complete list * * * not compiled * * *." Almost any 100-ml sample of Scioto River (Ohio) water, taken at the same time of year, will show from 60 to 120 plankton species alone. It is an inevitable conclusion that the highly acid waters greatly diminish the number of possible inhabitants therein.

A number of Indiana and Illinois strip pits have been dammed at various times, raising the water above the exposed coal seams and creating long and often deep and beautiful lakes. Here there is little or no chance for the oxidation of sulfur to sulfuric acid. The result is a very slow decrease in acidity and a subsequent slow repopulation of the lake by microorganisms, then by fish and other animals. The Tygart River at Phillipi, W. Va., gave a sample whose pH was 6.0 and which yielded 44 microscopic species on an incomplete examination. The river was clear and green at that point because of algae growing on submerged objects, yet a few years ago, before the sealing of mines in this region, it was a highly acid stream, "red and nothing would grow in it." No data were available on the succession of forms reinvading gradually improving streams or lakes, but copepod Crustacea were found in enormous numbers in two lakes, one with a pH of 6.6, and in the Tygart River. Because the strip pit lake is usually surrounded by high, steep banks and its total watershed area is hardly greater than the lake area, it must depend on photosynthetic protozoa and algae for fertility. The high, steep banks can contribute no humus for feeding the organisms initiating food chains, and either there are no shallow areas for growth of higher plants, or else the acid tolerant Typha preempts such areas and is, apparently, a poor "fertilizing" plant. The general impression is that recovery of a highly acid strip pit to a productive body of water is a slow process if left to nature.

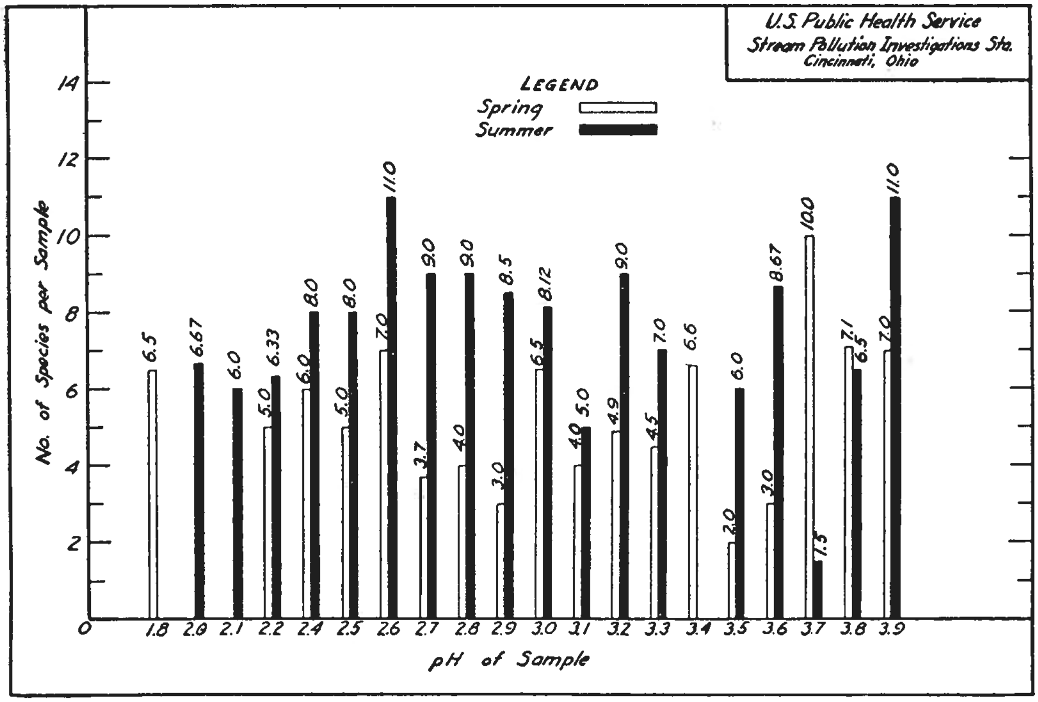


Figure 6 - Average number of species per sample within the pH range 1.8 to 3.9.

SUMMARY

Two coal mining regions, shaft mining areas in West Virginia, and strip mining areas in Indiana and Illinois, were visited and biological surveys twice made of their highly acid streams and strip pit lakes. A few adjacent almost neutral streams and lakes were surveyed for comparison.

A total of 86 species of microscopic forms was recognized. Besides Thallophyta, Protoza, and Trochelminthes, only one of the remaining phyla of plants and animals, the Arthropoda, was represented by more than one commonly occurring species in these acid waters.

At or below pH 3.9, the number of species found in any given habitat was very small. The largest number was 11 at pH 2.6 and several samples showed no life on examination.

Practically the same forms were common in April and October, but there was quite a difference in the species termed adventitious which were found at the two different times.

Seventeen species occurred in 15 percent or more of the samples and are termed "common." The most frequently occurring ones were as follows: Euglena mutabilis, Naviculoid diatoms, Chlamydomonas spp., Distyla sp., Actinophrys sol., Oxytricha sp., Ochromonas sp., and Ulothrix zonata.

Because the most sharply definitive factor, sulfuric acid acidity, remains relatively constant, the relative constancy of species occurrence indicates that this one factor outweighs all others.

After the strip pit lakes have been sealed to reduce acid production there appears to be little chance for them to become productive except by the initial development of a large flora and fauna of chlorophyll-bearing organisms. Inasmuch as seven of the 17 organisms most common in this environment belong to this category, this initial process is apparently already under way.

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A HEAVY MORTALITY OF FISHES RESULTING FROM THE DECOMPOSITION OF ALGAE IN THE YAHARA RIVER, WISCONSIN

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ABSTRACT

A heavy loss of fish occurred in the Yahara River below Lake Kegonsa, Wisconsin, during the latter part of September and the early part of October, 1946. All species of fish in the river were affected in the mortality. The fish, crowded close to shore, were breathing at the surface and showed marked signs of distress before expiring.

Chemical analyses of the water were made in successive periods, and experiments were performed to determine the toxicity of the river water to experimental fish. Death was attributed primarily to the depletion of the oxygen supply by the decomposing algal mass consisting of almost a pure culture of Aphanizomenon flos aquae. Secondarily, toxic substances liberated into the water by the decomposing algae probably contributed to the death of the fish.

INTRODUCTION

A heavy loss of fish occurred in that portion of the Yahara River from the Lake Kegonsa Lock downstream to its confluence with the Rock River during the latter part of September and the early part of October, 1946. Although many thousands of fish were observed, no estimate was made of the number. Carp (Cyprinus carpio) were the predominant fish affected. Other species observed were northern pike (Esox lucius), yellow pike perch or walleye (Stizostedion v. vitreum), black crappies (Pomoxis nigro-maculatus), bluegills (Lepomis macrochirus), suckers (Catostomus commersonnii), black bullheads (Ameiurus m. melas), buffalo (Ictiobus bubalus), hog suckers (Hypentelium nigricans), and an eel (Anguilla bostoniensis).

A series of eight representative stations was established in the 17 miles of river between the Lake Kegonsa Lock and the Rock River to study the progress of the mortality (Fig. 1).

PROGRESS OF THE MORTALITY

A huge algal mass estimated between three and four acres in area and several inches thick was moved into the bay above the Lake Kegonsa Lock by westerly winds and accompanying wave action on September 25, 1946. To prevent undesirable odors, the mass was permitted to pass through the lock by the lock tender over a 6-hour period. On September 28, 1946, it was reported that a heavy fish mortality was occurring at Stoughton, Wisconsin, 3-1/2 miles below the lock. Upon investigation many dead and dying fish were seen at Station 2. The fish that were still alive showed signs of acute distress and were packed close to the shore, gasping at the surface. The bay at this location provided a concentration point for fish which undoubtedly were driven out of deeper water by the oxygen deficiency caused by decomposition of the algal mass (Fig. 2). Dead fish were seen floating through the lock at Stoughton, Wisconsin, located at Station 3.

On October 1, 1946, mortality was apparent at Station 4 which is 2-1/2 miles below the previous station. Over 8,000 carp, averaging 4 pounds each, were crowded into a shallow, spring-fed stream about 500 feet long and 4 feet wide which empties into the Yahara River near this station. Above a natural fish barrier in the stream the water contained 9.6 p.p.m. of dissolved oxygen but in the lower portion there was no oxygen. The carp lived in the section of the stream where the oxygen supply remained adequate for their needs (Fig. 3).

On October 3, 1946, the mortality had reached Stations 5 and 6, located 8 miles down the river. The conditions found here were similar to those at the previous stations.

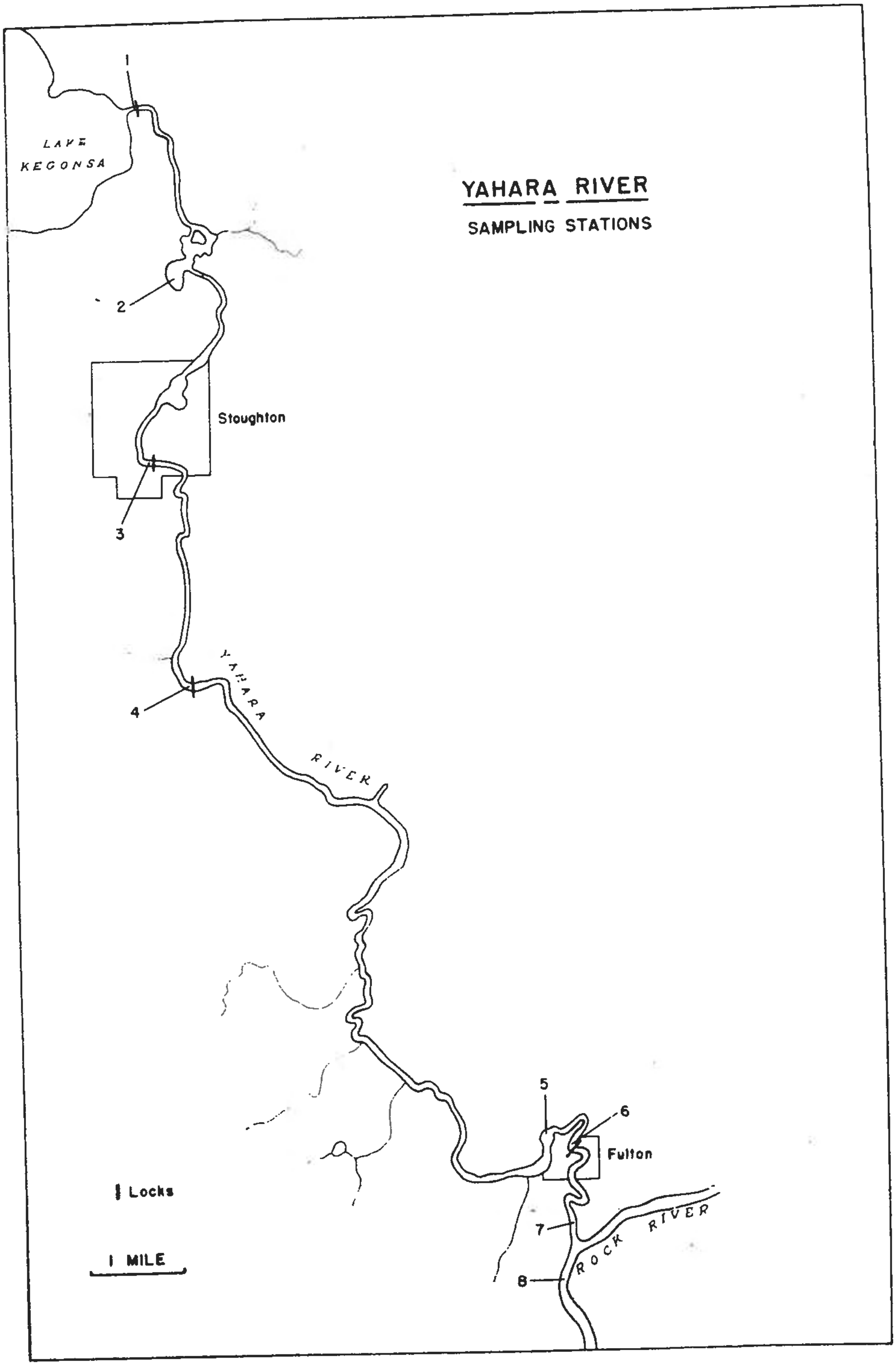

Figure 1 - Station locations on Yahara River, Wisconsin.

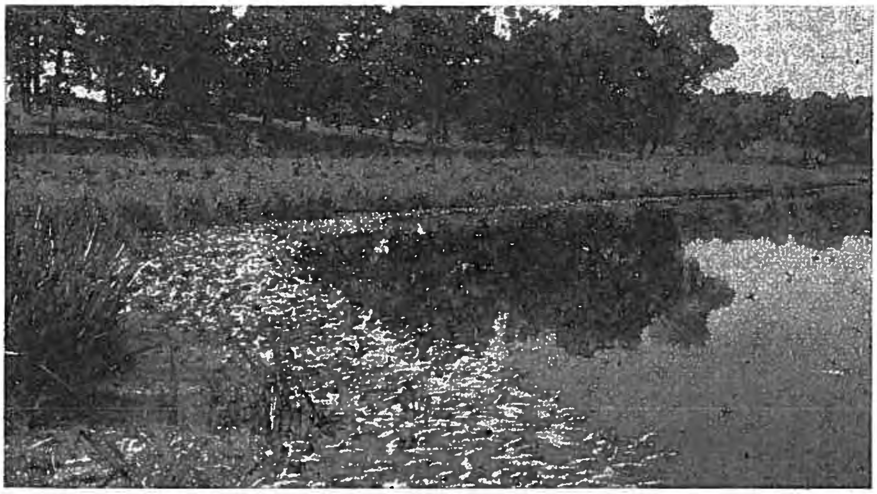

Figure 2 - Dead fish in bay of Yahara River.

Item	Date	Stations 1	2	3	4	5	6	7	8
Air temperature (F.°)	Sept. 28	....	58	58	....	....	....	....	....
	Oct. 1	66	66	66	....	....	....	....	....
	do. 3	....	72	72	72	72	72	72	72
	do. 5	....	68	68	68	68	....	....	....
	do. 9	....	66	66	66	66	66	....	....
Water temperature (F.°)	Sept. 28	....	62	62	....	....	....	....	....
	Oct. 1	64	64	56	....	....	....	....	....
	do. 3	....	64	58	59	60	60	60	60
	do. 5	....	62	63	61	64	....	....	....
	do. 9	....	62	60	61	61	61	....	....
Dissolved oxygen (p.p.m.)	Sept. 28	....	0.0	0.3	....	....	....	....	....
	Oct. 1	10.2	0.4	0.8	0.8	....	....	....	....
	do. 3	....	1.5	1.8	2.4	0.2	0.1	1.0	7.8
	do. 5	....	1.8	3.7	3.8	4.5	4.3	....	....
	do. 9	....	5.1	6.4	7.8	10.0	10.4	....	....
Free carbon dioxide (p.p.m.)	Sept. 28	....	43.0	30.0	....	....	....	....	....
	Oct. 1	0.0	17.5	7.0	7.0	....	....	....	....
	do. 3	....	14.0	5.7	5.5	11.5	14.4	8.0	0.0
	do. 5	....	3.5	2.0	3.0	2.0	4.0	....	....
	do. 9	....	1.0	0.0	0.0	0.0	0.0	....	....
Hydrogen-ion concentration (pH)	Sept. 28	....	7.0	7.0	....	....	....	....	....
	Oct. 1	....	7.2	7.3	....	....	....	....	....
	do. 3	....	7.3	7.7	7.4	7.4	7.3	7.4	....
	do. 5	....	7.6	7.6	7.6	7.6	7.6	....	....
	do. 9	....	7.7	8.0	8.0	8.4	8.4	....	....
Days of maximum fish mortality	Sept. 28	....	xxxx	xxxx	....	....	....	....	....
	Oct. 1	....	....	....	xxx	....	....	....	....
	do. 3	....	....	....	....	xxxx	xxxx	....	....

Table 1 - Temperature and chemical characteristics of Yahara River during the period between September 28 and October 9, 1946.

Figure 3 - Carp crowding into small spring-fed stream.

WATER CONDITIONS

An examination of the river water at the time of the fish mortality showed a concentration of the blue-green alga, Aphanizomenon flos aquae.

The results of temperature and chemical determination are shown in Table 1. At the time of greatest mortality, the oxygen content was less than 1 p.p.m., the free carbon dioxide was high, and the pH was low. It is believed that the depletion of oxygen in the river forced the fish into the shallow bays. The greatest fish mortality seemed to take place when the decaying algal mass moved downstream. Twelve days elapsed before the water returned to a condition suitable for fish life at Stations 2 and 3. The lower stations returned to normal more rapidly because there was greater dilution of the algal mass and more wave action.

EXPERIMENTS ON TOXICITY OF RIVER WATER

An attempt was made to determine experimentally the toxicity of substances in the river water. A sample of water was taken from Station 2 during the period of greatest mortality, placed in an aquarium, and aerated. A control was set up using aerated spring water. Two yellow perch (Perca flavescens) and two black crappies (Pomoxis nigro-maculatus) were placed both in the experimental and the control aquaria. After a period of 30 hours all experimental fish had died but the control fish were still living. The oxygen in the experimental tank at the end of the same period was 8.3 p.p.m.

On October 3, 1946, a similar experiment was conducted with water taken at Station 6, 14 miles down the river. Seven yellow perch, four black crappies and one common sucker (Catostomus commersonnii) were placed both in the experimental and the control aquaria. The yellow perch began to lose their equilibrium on October 6, 1946, and began to die on October 8, 1946. All of the fish in the experimental tank were dead on October 11, 1946, but the control fish remained alive. It is believed that the fish lived longer in this than in the earlier experiment because the algal mass was dispersed and the toxic substances diluted to such an extent that they were less harmful at the lower stations along the river.

CONCLUSIONS

It is concluded from the temperature and chemical data and from the results of experiments that the primary cause of the fish mortality was the depletion of the oxygen supply brought about by decomposition of a huge mass of Aphanizomenon flos aquae. Secondarily, toxic elements released by the decomposing algae probably increased the mortality.

An examination of the literature indicates that mortality produced by the decomposition of certain blue-green algae is not a new phenomenon. Fitch et al. (1934) who reviewed the literature on the effects of algal poisoning upon domestic animals pointed out that cattle, sheep, hogs, chickens, ducks, turkeys, and geese have been known to die soon after drinking water that contained a heavy algal growth. Rabbits and guinea pigs died suddenly after being inoculated intraperitoneally with algal suspensions extracted from live algae. Prescott (1939) stated that heavy growths of phytoplankton will deplete the oxygen supply during warm still nights and that the exhaustion of the oxygen brings about the death of both microfauna and phytoplankton. The decomposition by bacteria of this mass of organic matter quickly reduces further the oxygen content. As a result, the fish and other aquatic animals are suffocated. Prescott stated further that, "it is apparently possible for algae to bring about the death of fish through the liberation of substances toxic to them during the decay process. When highly proteinaceous blue-green algae undergo decay, sufficient quantities of hydroxylamine and other derivatives are produced to poison any fish caught in the shallow water of a bay by masses of decaying algae."

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SUGGESTED CLASSIFICATION OF ALGAE AND PROTOZOA IN SANITARY SCIENCE

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Many types of microorganisms are of real importance in the field of sanitary science. Bacteria, molds, yeasts, protozoa and algae all play significant roles in relation to water and sewage. A limited number of them are pathogenic but the great majority are those that cause nuisance conditions in water supplies or are associated with sewage treatment and stream self-purification.

CLASSIFICATION OF PIGMENTED FLAGELLATES

Confusion exists in the literature of sanitary science in the classification of a considerable number of microorganisms. The confusion is especially evident in dealing with certain organisms which are on the borderline separating algae of the plant kingdom from protozoa of the animal kingdom, where one investigator may classify a particular organism with the algae and another place the same organism with the protozoa (1) (2).

The organisms most often involved in this confusion are those known as pigmented flagellates which have both the protozoan characteristic of being able to swim by means of flagella, and the algal characteristic of photosynthesis made possible by the presence of the pigment chlorophyll. Thus, they are intermediate between typical algae and typical protozoa, and it would depend upon which characteristic was emphasized as to whether they would be listed in the plant kingdom as swimming, flagellate algae, or in the animal kingdom as photosynthetic pigmented* protozoa. It is the authorities in the fields of protozoology and algology who are responsible for the existing confusion, since they have come to no agreement as to the classification of the organisms involved.

In an attempt to resolve opinions among authorities concerned with the characteristics an organism should have in order to be classified as a protozoan or as an alga, a large group name, the Protista, was proposed by Haeckel (3). Under it all protozoa and all one-celled algae were lumped together without distinction. The term "Protista" has not received general recognition and would be of little or no value to the sanitary scientist.

EXISTING CONFUSION IN SANITARY SCIENCE

A recent book, "Water Quality Criteria" (4) serves to illustrate the existing confusion in classification of microorganisms. The pigmented flagellate, Synura is listed on page 170 as an alga, and later, on page 333, as a protozoan. Lackey (5) in his paper, "Protozoan Plankton as Indicators of Pollution in a Flowing Stream," referred many organisms to the protozoa that he, in other papers, classified as algae, (1) (6). Turre (7), who has published photomicrographs of algae in water supplies, includes Volvox with the green algae, while Dinobryon and Synura are listed under protozoa. He considers the protozoa as one group of algae.

Mohr (8), in his paper on protozoa as indicators of pollution, lists the chlorophyll-bearing Euglena with the organisms Paramecium and Vorticella, which are nonpigmented protozoa. Brinley (9) lists the pigment-containing Ceratium and Peridinium as protozoa. Thomas and Grainger (2), in their book, "Bacteria," refer the pigmented flagellates Chalmydomonas, Uroglena, Synura, and Dinobryon, to a class of protozoa, the Mastigophora. Cox (10), in his book, "Laboratory Control of Water Purification," lists the following as protozoa: Dinobryon, Euglena, Uroglena, Synura, and the unrelated nonpigmented protozoan parasite Endamoeba histolytica. Hale (11), in recommending chemicals required for control of organisms, lists ten genera, including Chlamydomonas, under protozoa with only two nonpigmented genera in the list, namely, Bursaria and Endamoeba. Other pigmented flagellates, including Pandorina and Volvox which are closely related to Chlamydomonas, are placed with the algae. Hopkins (12) lists ten genera of chlorophyll-bearing organisms under protozoa in a table reproduced from Hale (13). Whipple, Fair, and Whipple (14) list some of the pigmented flagellates as protozoa and others as algae. In "Water Quality Criteria" (4), Synura, Dinobryon, and Uroglenopsis, all containing photosynthetic pigments, are listed under protozoa in a discussion of domestic water supplies along with such true nonpigmented protozoan parasites as Endamoeba histolytica and Balantidium coli. Pigmented forms such as Gymnodinium, Gonyaulax and Peridinium

* "Pigmented" refers to chlorophyll and other photosynthetic pigments only.

are listed as protozoa in a discussion of their relation to fish and shellfish mortality. Gonyaulax catenella, a pigmented form responsible for mussel poisoning, is considered only as a protozoan.

Writers in the field of sanitary science who have placed pigmented flagellates under the algae include Kehr et al. (15), Hobbs (16), Prescott (17), Brinley and Katzin (18), Gainey and Lord (19), and Sorensen (20). Modern workers in the field of algology also follow this practice, including Fritsch (21), Smith (22), Tiffany and Britton (23), and Prescott (24).

SIGNIFICANCE OF OXYGEN-PRODUCERS

The relationship of microorganisms, including the flagellates, to oxygen is particularly significant, especially when considering their role in treatment of sewage and in stream self-purification. The amount of dissolved oxygen is one of the limiting factors in determining the speed with which microorganisms will bring about the modification of sewage in a treatment plant or of organic wastes in a stream.

It is assumed from results of research, to date, that all organisms containing chlorophyll and other related pigments are capable of carrying on the process of photosynthesis. In this process the organisms remove carbon dioxide and water from the environment and, in the presence of light, produce oxygen and carbohydrates. Much of the oxygen is released by the organism into the water, whereas the carbohydrate is retained. The photosynthetic organisms are therefore recognized as oxygen producers.

Nonphotosynthetic organisms undergo no process by which oxygen would be released into the water. These nonpigmented forms carry on the process of respiration in which the relationship of carbon dioxide and oxygen are the opposite to that in photosynthesis since available oxygen from the environment is utilized and carbon dioxide is released. The pigmented organisms also carry on respiration in addition to photosynthesis, but during the hours of daylight the latter takes place at a much higher rate. The supersaturation of natural waters with oxygen, which is frequently encountered, is usually a result of photosynthesis. In darkness, with no photosynthesis taking place, the pigmented organisms behave in a manner similar to the nonpigmented, both groups using oxygen and releasing carbon dioxide. When the sum of the effects occurring in a typical diurnal-nocturnal cycle are considered, however, the pigmented organisms are recognized as oxygen-producers and the nonpigmented ones as oxygen-consumers. If present and active in large numbers, the oxygen-producers stimulate oxidation of organic wastes by the oxygen-consuming organisms. Both oxygen-producers and oxygen-consumers, therefore, are distinct and important groups of microorganisms for the sanitary scientist to consider.

This relationship of microorganisms to oxygen is also utilized as one of the basic characteristics in their classification. Typical algae are described as oxygen-producers, and the typical molds, protozoa, yeasts, and bacteria as nonoxygen-producers or oxygen-consumers. The confusion in the classification occurs when this characteristic is not given sufficient emphasis.

A SOLUTION TO THE PROBLEM

When the oxygen and non-oxygen producers are mixed together in a classification, it is not possible to evaluate clearly their roles in water pollution problems. As has already been indicated, this type of confusion is evident in connection with the classification of the pigmented flagellates. For the sanitary scientist, it would not be difficult to overcome the confusion, because to him the oxygen-production of these organisms needs to be taken into consideration, whereas their swimming ability is of little or no importance. The sanitary scientist, therefore, should logically group the pigmented flagellates with the photosynthetic algae rather than with the nonpigmented protozoa.

In actual practice it might be difficult or impossible to recognize oxygen-production by individual organisms were it not for the fact that the visible characteristic of pigmentation is associated with that physiological phenomenon. These organisms normally possess the green chlorophyll and frequently additional pigments in amounts sufficient to be visible under a compound microscope. The pigments are located within the protoplasm of the individual cells and can be seen to be localized within the cells of the organisms in the form of one or more plastids or chromatophores. The other pigments which may be present in addition to the chlorophyll lend various shadings of color to the plastids in the cells. The shades most frequently encountered in the pigmented flagellates are green, yellow-green, and brown. Examples of some of the pigmented flagellates with their plastids or chromatophores are illustrated in Figure 1, together with some non-pigmented flagellates. It will be noted that, in either group, both unicellular and colonial types are to be found.

In addition to the sanitary scientist's need to separate organisms according to their oxygen relationship, it is desirable from another standpoint to have all organisms grouped according to one recognized classification in order to eliminate the wasteful duplication of effort. For example, if the same swimming, pigmented organism is causing an undesirable odor in a settling basin at a water treatment installation in Iowa and at another in South Dakota, it is a handicap to have the organism listed as an alga at one place and as a protozoan at the other. Because of the presence of the photosynthetic pigment, it is recommended that all workers list it as an alga. Coming to such an agreement would do away with doubt that may arise in comparing effective control measures put into practice in each area.

NONPIGMENTED FLAGELLATES

A second small group of flagellates is involved in the confusion over classification. A few nonpigmented, swimming organisms are considered by authorities to be so closely related to the pigmented swimming forms that they are often placed in the same groups with the latter rather than with other nonpigmented forms.

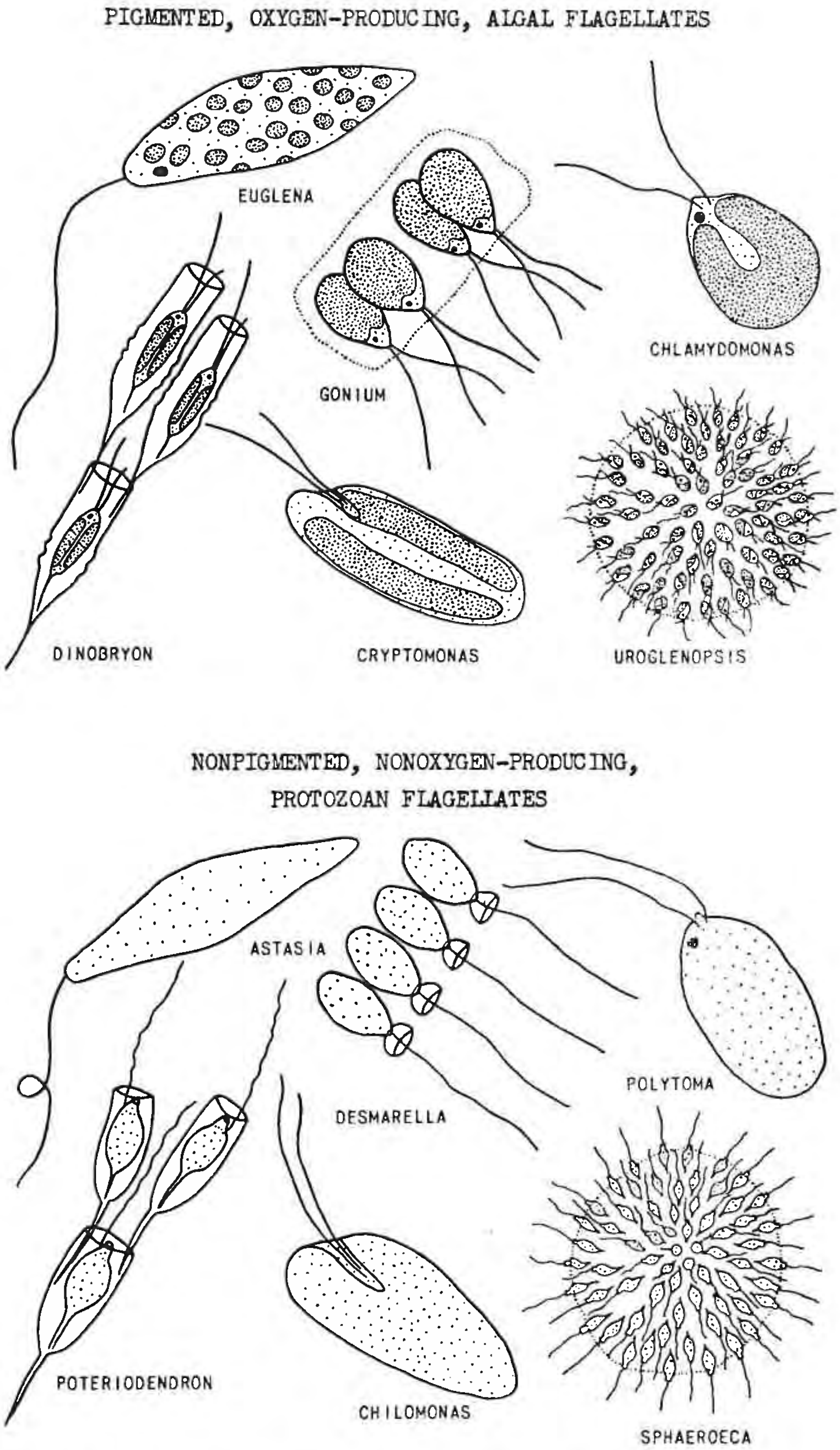

Figure 1 - Typical pigmented and nonpigmented flagellates.

Included among the nonpigmented flagellates, which have been involved in the confusion, are such genera as Astasia, Polytoma, Chilomonas, Euglenopsis, and Peranema. Thus, an algologist would consider these particular nonphotosynthetic organisms to be algae, just as many protozoologists have considered the pigmented flagellates to be protozoa.

Again, the sanitary scientist can settle this problem for himself by placing all nonpigmented (nonoxygen-producing) flagellates with the protozoa, disregarding the close evolutionary relationship between certain pigmented and nonpigmented forms.

RECOMMENDED GROUPING OF FLAGELLATE FORMS

Table I which follows, separating flagellates into two easily recognizable groups, can serve as a guide to classification for those working in sanitary science, and thus, make it possible to overcome the existing confusion. The first group includes the pigmented, photosynthetic, oxygen-producing, "algal" flagellates. The second group includes the nonpigmented, nonphotosynthetic, nonoxygen-producing, "protozoan" flagellates. In a very few cases, certain species of the genera in the first list are nonpigmented. These particular species would, of course, need to be placed in the second list.

More than 150 genera of flagellates have been reported for the United States. Some of these forms are comparatively rare and are of little or no importance to sanitary scientists. Others, however, are included among the microorganisms frequently encountered in water supplies or sewage. Organisms listed are limited to those flagellates which are considered to be of significance to the sanitary scientist.

SUMMARY

A lack of agreement exists among botanists and zoologists as to a definite line of demarcation between algae and protozoa. Consequently, there is no uniformity in the classification of a considerable number of flagellates which are important in the field of sanitary science. It is recommended, therefore, that the presence or absence of photosynthetic pigments (indicating the ability or inability to produce oxygen) be used in this field of applied science to separate the flagellates into the pigmented (algal) and nonpigmented (protozoan) types.

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TABLE I.—Classification of Flagellates

Pigmented, oxygen-producing "algal" flagellates		Nonpigmented, nonoxygen-producing "protozoan" flagellates	
Carteria	Hemidinium	Anisonema	Mastigamoeba
Ceratium	Lepocinclis	Anthophysis	Mastigella
Chlamydomonas	Mallomonas	Astasia	Menoidium
Chlorogonium	Ochromonas	Bicosoeca	Monas
Chromulina	Pandorina	Bodo	Monosiga
Chroomonas	Peridinium	Cercobodo	Noctiluca
Chrysococcus	Phacotus	Cercomonas	Notosolenus
Chrysosphaerella	Phacus	Chilomonas	Oikomonas
Colacium	Pleodorina	Clautriavia	Peranema
Cryptoglena	Pteromonas	Codonosiga	Petalomonas
Cryptomonas	Pyramimonas	Cyathomonas	Pleuromonas
Dinobryon	Pyrobotrys	Desmarella	Polytoma
Dunaliella	Rhodomonas	Dinema	Polytomella
Eudorina	Spondylomorum	Dinomonas	Poteriodendron
Euglena	Synura	Distigma	Rhabdomonas
Eutreptia	Trachelomonas	Entosiphon	Sphaeroeca
Glenodinium	Uroglena	Euglenopsis	Tetramitus
Gonium	Uroglenopsis	Heteronema	Trepomonas
Gonyaulax	Volvox	Hexamita	Tropidoscyphus
Gymnodinium	Wislouchiella	Hyalogonium	Urceolus
Haematococcus		Khawkinea	

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